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The Atomic Industry and Human Ecology

V—THE AIR WE LIVE IN

IN THIS SERIES of brief essays, the concern of NUCLEONICS is to explore many aspects of the impact of atomic energy on man, that is, to focus attention on human ecology in our field. Since the atomic industry is new, one may expect to find, as indeed are being found, many new problems and changed emphasis on old problems. Some of the more interesting are directly related to the air we live in. In this issue of NUCLEONICS, for example, the editors present the first in a series of articles concerned with the air pollution and particle-size problem as it refers to concentrations that may be toxic to man.

The air we live in, or the earth's atmosphere, is a mixture of nitrogen, oxygen, and argon primarily, but with large local variations in the quantities of carbon dioxide, water vapor, liquid water, solid water (ice or snow), other gases (neon, helium, radon, *etc.*), and impurities or pollutants of every particle, element, and compound known to man. Up to an elevation of about 12 miles the relative amounts of nitrogen, oxygen and argon are 75.51, 23.15 and 1.28 per cent, respectively, by weight almost uniformly everywhere; at very great elevations the lighter gases predominate.

Even before man lived on earth there were large variations in the amounts of the various constituents other than nitrogen, oxygen, and argon, which for simplicity we have grouped together as pollutants. Similar large variations in the amounts of water as vapor, liquid and solid, from place to place and from time to time, are shown by records of erosion. The study of many of these variations is in the science of geophysics, with branches in meteorology, oceanography, hydrology, seismology, *etc.* The biological and chemical sciences must be included if one wishes to make the study complete. For an understanding of the atmosphere requires investigation not only of its (variable) constitution but also of the media bounding the atmosphere—earth and space—and of the energy and/or matter passing through it, and of all their interactions.

Atmospheric pollution and the atomic industry are related by a number of facts, among which the extremely small concentrations of beryllium that may be toxic is important because of the increased production of beryllium metal required for atomic-energy development. The atmosphere is not confined to definite boundaries, and any pollutant whatever released into it may perform any one or more of several embarrassing evolutions; the result may be more than embarrassing if the course of the pollutant is away from the property of the source, whether this be to go from one chemist's hood, say, to annoy management in its offices, or from the plant entirely to become a nuisance or a threat to the surrounding public.

Other important considerations suggest themselves, especially if the pollutant is radioactive and has a long half-life. Even if the effluent from the source in question is gaseous and quickly decays to a normal atmospheric constituent, care must be exercised to prevent personnel from getting more than the permissible dose from its gamma rays. If any particulate matter is released to the atmosphere, one must face the additional fact that some will be "washed out" by rain or snow. The particles may be few and small, but still accomplish damage either by coming into direct contact with man, or by coming to him indirectly from some other plant or animal.

Whatever the care taken to decrease the possibility of any effluent containing any radioactive matter in the smallest degree, there is no reason for complacency unless the operator knows the following: (1) the amount of pollutant released to the atmosphere, and (2) the complete course of the pollutant's history from the time it leaves the property of the source until it is diluted or has decayed to concentrations less than the established permissible dose. These two things should be known not only for normal operating conditions, but for any accidental spill or disaster as well. The irreducible minimum of knowledge that is acceptable should be certainty that the greatest possible hazard is less than a known (and recorded with proper authority) quantity.

Two important questions arise immediately. What are the permissible doses of radiation under various circumstances? And how does one know the complete course of the pollutant? The fact that neither question can be answered once for all times, sources, persons, and states of the atmosphere rather makes the matter more worthy of attention by good men and brains than discouraging. The fact remains that for any particular source of radiation, for any particular biological specimen, and for any particular state of the atmosphere, one may determine proper answers to both questions—answers either for a long peace or for war, two extremes in which the calculated risk society will accept may be quite different.

The important thing is that some permissible dose be set by some authority and widely published and enforced forthwith. Scientists themselves working with atomic energy are not logical candidates to establish permissible-dose figures; they must be consulted and their reports heard. But only the highest echelon of top management and government is in position to weigh all relevant factors. These few are responsible to the many in our democracy, and that responsibility is discharged only by the widest possible publication of the values established, with the opinions on which the permissible dose is set also published, whether or not they agree.

Once the permissible dose is established for various regions and sources, the scientist and engineer (specifically including those meteorologists and others who have experience in atmospheric pollution studies) are available to decrease the effluent from any radiation source to the lowest possible value, and then to determine its complete course in the atmosphere until it is certainly harmless. These problems are not simple and easy of solution; they are capable of solution and they must be solved.

Note: The preceding editorials in this series devoted to the subject of "The Atomic Industry and Human Ecology" were entitled: I—Waste Disposal (August, 1949); II—On Risk (September, 1949); III—On Getting the Word (October, 1949); IV—Relax (November, 1949).

Neutron Spectroscopy for Chemical Analysis—I

NEUTRON PROPERTIES, INTERACTIONS, VELOCITY SELECTION

A general introduction to and review of the subject, together with a discussion of resonance absorption, slow variation in cross section with neutron energy, thermal neutron transmission and absorption, neutron diffraction, and neutron activation

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THE EXISTENCE of the neutron was first demonstrated by Chadwick (*1*) in 1932. Since then a number of methods have been devised for liberating them from nuclei (*2*) and for detecting them. The unique properties of neutrons and their interactions with matter have been studied extensively because of their importance in development of the nuclear energy program. Depending upon the energy of the neutrons, they may interact with matter in a variety of ways. Some of these interactions have been found useful for chemical analysis.

Properties of Neutrons

Since neutrons are neutral particles (charge $Z = 0$), they might be considered the element of zero atomic number. They have a rest mass m of 1.00894 atomic mass units, which is slightly greater than the mass of the proton, 1.00758. Neutrons have half-integral spin ($I = \frac{1}{2}$), follow Fermi-Dirac statistics, and possess a negative magnetic moment of -1.9103 nuclear magnetons. There is some evidence that free neutrons are unstable and decay into protons, electrons, and neutrinos with half-lives of about 15 minutes.

Neutral character. The neutral character of neutrons allows them to pass through matter much more readily than do charged particles. They can, for example, approach and enter a nucleus without having to overcome repulsive electrical forces. Consequently, high velocity is not a prerequisite for nuclear reactions as it is in the case of charged particles. In fact, slow neutrons are more effective than fast neutrons in producing certain nuclear reactions.

When charged particles pass through matter, ionization results; this affords a means of detecting the path of the particles. Since neutrons have no charge, there is very little interaction with the external electrons of the atom as they pass through matter. A very slight interaction with the electrons of atoms arises from the magnetic moment and the structure of the neutron itself, but this produces negligible ionization. However, neutrons with sufficiently high energies can knock protons from hydrogen-containing materials such as paraffin. Indeed, the existence of this process led to the discovery of neutrons and now is one of the methods of detecting high-energy neutrons.

Prolonged irradiation of matter with neutrons may produce changes in such properties of the matter as color, thermal conductivity, or electrical

conductivity. This is caused by displacements of atoms from their normal positions. In the case of organic materials, chemical bonds may be broken, resulting in the decomposition of the molecule (*3*).

Detection. Because of their neutral character and because they do not themselves produce a significant amount of ionization in passing through matter, slow neutrons must be detected by their interaction with nuclei. As will be discussed more fully later, neutrons induce artificial radioactivity in many elements. For example, foils of indium, gold, silver, rhodium, manganese, *etc.*, are made radioactive when placed in a flux of neutrons, as illustrated by the following reaction:

$$Mn^{55} + n \rightarrow Mn^{56} \xrightarrow[2.59\ hr]{\gamma} Fe^{56} + \beta^- \text{ (2.8 Mev)}$$

The intensity of the induced radioactivity is dependent, among other things, upon the number of neutrons that enter the foil. Silicon, as well as a number of other elements, may be used for detection of fast neutrons:

$$Si^{28} + n \rightarrow Al^{28} \xrightarrow[2.3\ min]{p} Si^{28} + \beta^- \text{ (3.0 Mev)}$$

The energetic β^- particles, which can readily be detected, indicate the presence of fast neutrons.

Another more useful method of detecting slow neutrons is by means of an ionization chamber which contains BF_3 gas or whose walls are coated with boron or lithium. Here the ionization produced by the energetic particles liberated in the following reactions is a measure of the neutron intensity:

$$B^{10} + n \rightarrow Li^7 + \alpha \quad \text{and}$$

$$Li^6 + n \rightarrow H^3 + \alpha$$

Most neutron detectors are now proportional-type counters filled with boron trifluoride (BF_3) enriched in the B^{10} isotope. Such counters may be obtained from a number of manufacturers of radioactivity equipment.

In addition to the methods of detection already given, the ionization resulting from the fission of uranium is also useful, particularly if the uranium is enriched with the 235 isotope.

Wave-like properties. In their interactions with matter, neutrons seem to act as particles in some respects and as waves in others, just as is found in the case of electrons, for example. Thus, when a neutron is moving with a velocity v meters per sec, it has associated with it a wavelength of $\lambda = h/(mv)^* = h/\sqrt{2mE}$ or $\lambda(\text{Angstrom units}) = 3.96 \times 10^3/v$. That is, the wavelength varies as $1/v$, a relation significant in the effect of velocity on slow neutron interactions. Frequently the kinetic energy of the neutron is given in terms of electron volts,† E. In this case, the velocity in meters per sec is $v = 1.383 \times 10^6 \times \sqrt{E}$ and the wavelength is $\lambda = 0.286/\sqrt{E}$ A.U. Thus a neutron with an energy of one electron volt (1 ev) has a de Broglie wavelength of 0.286 A.U.

When neutrons are slowed down so that their energies are approximately that of gaseous molecules at room temperature (27° C), they are called thermal neutrons. Their most probable velocity is about 2,200 meters per second, 0.026 ev. This corresponds to a wavelength of about 1.8 A.U., which is of the order of the internuclear distance between atoms. Consequently, diffraction effects result

* Where h is Planck's constant.

† One electron volt is the energy acquired by an electron which falls through a potential difference of one volt. The electron acquires a velocity of 5.931×10^7 cm per sec and an energy of 1.602×10^{-12} ergs. This is equivalent to 96,480 joules per mole or 23,055 cal per mole. A neutron with one electron volt of energy would have a velocity of $v = 13{,}830$ meters per sec.

when neutrons in this energy range are coherently scattered by crystals. The angular distribution of the diffracted neutrons obeys the same Bragg expression, $n\lambda = 2d \sin \theta$, that is used for X-rays (*4*).* Neutron diffraction has been applied to the study of crystal structure in much the same way as X-ray diffraction. These applications will be discussed in a later section.

Interesting and useful variations exist in the interaction of neutrons with matter as their energy is decreased from a few million electron volts to energies as low as 0.001 ev. At certain neutron energies, marked differences exist among the elements, and indeed among the isotopes of a given element. These differences make it possible to develop methods of analysis for certain elements and isotopes, as will be outlined in a later section. Quantitative statements relative to the magnitude of the different types of neutron interactions are usually given in terms of "cross sections."

Cross Sections for Neutron Interactions

When an essentially unidirectional beam of neutrons is incident on a sample of material, some of the neutrons pass through unaffected and the others are either absorbed or scattered from the beam as a result of neutron interactions. This attenuation of the neutron beam can be determined in a suitable experimental arrangement shown diagrammatically in Fig. 1. The fractional decrease in intensity dI/I_x of a neutron beam in passing through a layer dx (Fig. 1) is equal to the ratio of the *effective area* of the nuclei in the layer to the *total area* of the layer. The effective area presented by the nuclei is given by the total effective cross section σ_t of each nucleus times the number of nuclei

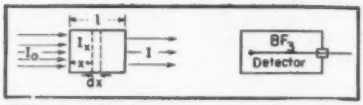


FIG. 1. Neutron cross sections from transmission measurements; I_0 = initial neutron intensity; I_x = neutron intensity at x; l = thickness of sample

in the layer or $\sigma_t n A dx$, where n is the number of nuclei per cc and A is the area. Hence $dI/I_x = -\sigma_t n A dx/A = -\sigma_t n dx$ from which

$$I = I_0 e^{-\sigma_t n l} \qquad (1)$$

where I_0 is the initial intensity of the neutron beam and I is the intensity after it has passed through the sample of thickness l. Hence, the total cross section per nucleus in cm² can be calculated from the results of transmission measurements by using Eq. 1 in the form

$$\sigma_t = \frac{1}{nl} \ln \frac{I_0}{I} = \frac{1}{nl} \ln \frac{1}{T}$$

Since the number of atoms per cc is given by $\rho N/M$, where M is the atomic weight, ρ is the density, and N is Avogadro's number,

$$\sigma_t = \frac{M}{\rho N l} \ln \frac{I_0}{I} = \frac{M}{\mu N} \ln \frac{I_0}{I} \qquad (2)$$

in which μ is the grams per square centimeter of the element in the path of the neutron beam.

The cross section obtained in this way is the total cross section for all processes which tend to deflect the neutrons from their straight line of flight. Charged-particle scattering measurements and the lifetime-energy relationship in heavy-charged-particle emitters indicate that the actual physical radius of an element of mass number A is given approximately by $1.5 \times 10^{-13} \times A^{1/3}$. For an element of mass number of about 125, the radius of the nucleus would be 7.5×10^{-13} cm or a cross section of about 1.8×10^{-24} cm² (1.8 barns). Cross sections for neutrons may vary from this value

* Where n is the order of reflection, d is the distance between atomic planes, and θ is the angle of incidence with the plane or angle of reflection.

TABLE 1

Types of Neutron Interactions

$\sigma_t = \sigma_a + \sigma_s$

Total =	*absorption processes*	+	*scattering processes*
	n,γ		Elastic nuclear scattering
	n,p		Inelastic nuclear scattering
	n,α		Resonant nuclear scattering
	n,d		Coherent crystal (diffraction)
	Also		Ferromagnetic scattering
	$n,2n$		Paramagnetic scattering
	n,fission		Inelastic molecular scattering
			Neutron-electron scattering

up to over 115,000 barns for gadolinium at a neutron velocity corresponding to an energy of about 0.002 ev. That is, the cross section of this nucleus at certain energies is many thousands of times larger than its actual physical cross section. Since the observed cross sections depend so markedly upon the particular nucleus and upon the velocity of the neutrons, it becomes necessary to examine more closely the processes that contribute to the cross section.

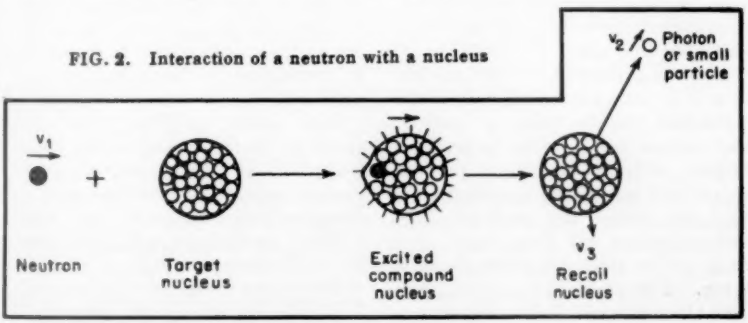
Types of Neutron Interactions

The compound nucleus. One of the generally adopted views of nuclear interactions is based upon Bohr's idea (*5*) of the compound nucleus as illustrated in Fig. 2. On the basis of this picture a neutron which comes close enough to a nucleus to interact with it actually unites with it to form a new compound nucleus. This new nucleus, excited by both the kinetic energy of the neutron and by the binding energy of the neutron with the nucleus (8 to 9 Mev) may change to a more stable state in any one of a variety of ways. The relative probabilities for the different possible reactions is usually described in terms of "reaction widths," Γ_x (*6*). The total cross section σ_t obtained from transmission is the sum of the cross sections for all of the reactions which take place.

A summary of a number of the important types of neutron interactions is given in Table 1.

Absorption. In absorption reactions, the excited compound nucleus changes to a more stable state by retaining the incident neutron and emitting either a photon (γ) or one of the other

FIG. 2. Interaction of a neutron with a nucleus



particles listed. Because charged particles must penetrate the potential barrier of the nucleus before they can escape, the (n,p), (n,d) and (n,α) reactions occur primarily with high-energy neutrons and with elements of low atomic number. The (n,γ) reaction is by far the most common absorption process, particularly for slow neutrons. This reaction is frequently called radiative capture, because the γ-ray is emitted from the compound nucleus very shortly after it is formed ($\sim 10^{-14}$ sec). The atomic number of the nucleus does not change in this process, but the mass number increases by one unit. Usually, if the isotope formed does not normally exist in nature, it will be radioactive. Over 150 radioactive isotopes (7) have been formed by the (n,γ) reaction, many of which have properties suitable for use in the radioactivation method of analysis to be discussed later.

Scattering. When a neutron rather than another particle is emitted from the compound nucleus, scattering results and the process is called an (n,n) reaction. The neutrons are emitted nearly isotropically from the compound nuclei, and consequently very few of them reach the detector if *good geometry* is maintained. For good geometry, the incident neutron beam should be essentially parallel and the detector should be sufficiently distant from the sample that it subtends only a negligible solid angle.

Inelastic scattering. If the nucleus is left in an excited state after the compound nucleus emits a neutron, the reaction is said to be an inelastic nuclear collision, because a part of the kinetic energy of the neutron is used to excite the nucleus. This excited nucleus will then return to a more stable state by emission of a γ-ray. The probability of such collisions increases with increasing neutron energy; it becomes significant for the heavy elements only above 0.1 Mev, and, for the lighter elements, above 1 Mev. Consequently, the slowing down of neutrons by this process is appreciable only for fast neutrons. Slow neutrons are involved in inelastic molecular collisions when they collide with a molecule and a part of their kinetic energy is used up in breaking chemical bonds, or in exciting higher vibrational and rotational energy states of a molecule. On the other hand, sub-thermal neutrons may receive energy from the molecular motions of molecules.

Elastic scattering. When the kinetic energy of the neutron and the nucleus remain constant, the collision is called an elastic one. In such collisions with heavy nuclei, the neutron leaves the compound nucleus with practically the same energy that it had prior to the collision. With light nuclei, however, the energy is distributed between the scattered neutron and the nucleus. In a head-on collision with hydrogen, where the masses are nearly equal, the laws of conservation of energy and momentum require that practically all of the energy be transferred to the hydrogen atom. At higher energies some protons are produced, and their maximum range can be measured to give the energy of the incident neutrons. If the collision is not head-on, the energy transfer will not be as great. On the average, however, about one half of the energy of fast neutrons will be transferred to the proton at each collision.

Such elastic collisions with light nuclei is the main process by which fast neutrons are slowed down to thermal velocities. Neutrons with an energy of one million electron volts (1 Mev), for example, are slowed down on the average to thermal energies (0.026 ev) by about 18 collisions with H, 40 with He, 80 with Be, 110 with C,

and 2,100 with U. A thickness of about 5 cm of paraffin would be required for this slowing-down process. If the neutrons do not escape from the paraffin, they are ultimately absorbed by the hydrogen and to a lesser extent by carbon. The mean free path of thermal neutrons in paraffin is about 0.3 cm, and their average life is about 200 μsec.

Variations in Cross Sections with Neutron Velocity

It is well known that marked variations exist in the cross sections for neutron interactions as the velocity of the neutron is changed. At high energies (1 Mev) where the wavelength of the neutron is of the same order of magnitude as the radius of the nucleus ($\lambda \approx R$), the effective total cross section is roughly twice the geometric size of the nucleus or $2\pi r^2$ as measured by other methods, *i.e.*, from 1 to 10×10^{-24} cm² (1 to 10 barns). In this high-energy region, the principal processes involve particle emissions, primarily scattering [(n,n) reactions]. However, there are some (n,p) and (n,α) reactions. As the energy of the neutrons is decreased, the cross section increases approximately as $1/v$, as illustrated in Fig. 3.

Resonance absorption and scattering. Many of the elements, particularly those with atomic masses above 100, show regions of resonance absorption and scattering where a marked increase in cross section occurs at definite neutron energies (Fig. 3). One or more of these resonances exist for many nuclei. The fact that they occur at specific neutron energies may serve as an indication of the presence or absence of a particular nuclear species in an unknown sample. Furthermore, the large cross section at resonance is useful in quantitative determinations of a limited number of elements, some of which can be determined chemically only with difficulty. Examples will be given in a later section.

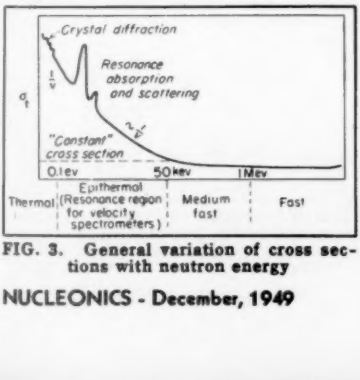


FIG. 3. General variation of cross sections with neutron energy

The shape of the resonance curve is given by the Breit-Wigner formula (*8*). The cross section at an energy E (electron volts) in the region of a resonance for an (n,γ) reaction is:

$$\sigma_{(n,\gamma)} = \frac{\lambda^2}{4\pi} g \frac{\Gamma_n \Gamma_\gamma}{(E - E_0)^2 + (\Gamma/2)^2} \quad (3)$$

where λ is the wavelength [$\lambda = h/(mv)$] of the incident neutron, and g is a statistical weight factor for the spins of the target nucleus, the compound nucleus, and the neutron. Γ_n is the partial level width (proportional to the reaction probability) of the (n,n) process. It is convenient to include the value of g in this neutron width. Γ_γ is the partial level width with respect to the (n,γ) process. $\Gamma = \Gamma_n + \Gamma_\gamma$ is the full width of the resonance peak at half its maximum value σ_0. E is the energy of the incident neutron, and E_0 is the resonance energy.

For low-velocity neutrons, Γ_γ is nearly independent of velocity while Γ_n is proportional to v. The maximum possible cross section for the (n,γ) process would be

$$\sigma_{0(n,\gamma)} = \frac{\lambda^2}{\pi} \cdot \frac{\Gamma_n \Gamma_\gamma}{\Gamma^2}$$

or $\lambda^2/4\pi$ at $E = E_0$ if $\Gamma_n = \Gamma_\gamma$. This would be a possible total cross section of $\lambda^2/2\pi$ for the sum of both $\sigma_{0(n,\gamma)}$ and $\sigma_{0(n,n)}$. A few nuclei (*9*) such as Pd^{108}, Sm^{152} and W^{186} appear to have levels in which $\Gamma_\gamma \approx \Gamma_n \approx 0.1$ ev.

Resonance capture. In most cases, however, $\Gamma_n < \Gamma_\gamma$ by a factor of 10 to 100, so that $\Gamma_\gamma \cong \Gamma$, and the maximum possible cross section for resonance absorption is $\sigma_0 = \lambda^2/\pi(\Gamma_n/\Gamma_\gamma)$. Since Γ_n varies as the velocity v or as $\sqrt{E}$, the cross section $\sigma_{(E)}$ for an energy E other than the resonance energy can be obtained by bringing Eq. 3 into the following form:

$$\sigma_{(E)} = \left(\frac{E_0}{E}\right)^{1/2} \frac{\sigma_0 \Gamma^2}{4(E - E_0)^2 + \Gamma^2} \quad (4)$$

At energies low compared to E_0, Eq. 4 shows that $\sigma_{(E)}$ is proportional to $1/\sqrt{E}$ or to $1/v$. This is the well-known $1/v$ law. Examples of the above are Rh^{103}, In^{115}, and Au^{179} in which Γ_γ is about 0.1 ev compared to 0.001 ev for Γ_n.

Resonance scattering. The cross section $\sigma_{(n,n)}$ for elastic scattering of low-energy neutrons in the region of a resonance is

$$\sigma_{(n,n)} = \frac{\lambda^2}{\pi} \times \frac{\Gamma_n^2}{4(E - E_0)^2 + \Gamma^2} \quad (5)$$

which, at the resonance energy E_0, gives a maximum cross section of λ^2/π. There are cases of levels such as in Mn and Co in which scattering is the more favored process, $\Gamma_n \approx 5$ ev and $\Gamma_\gamma \approx 0.1$ ev.

The $1/v$ region. At low energies, the cross section for scattering varies as $(\lambda^2/\pi) \times (\Gamma_n^2/4E_0^2)$, and since λ varies as $1/v$ and Γ_n varies as v, the scattering cross section should be fairly constant. Hence, the total cross section $[\sigma_{total} = \sigma_{capture(n,\gamma)} + \sigma_{scattering(n,n)}]$ in the $1/v$ region is made up of a constant scattering term plus a capture term that varies as $1/v$ or as $1/\sqrt{E}$. Thus, the cross section in this region can be expressed by an equation of the form $\sigma_{(E)} = a + b/v$. The magnitudes of the absorption cross sections in this region, as well as the slopes of the $1/v$ curves, differ for a number of the elements. Consequently, a method of analysis of certain simple systems can be based on these properties.

Molecular effects. In the case of the lighter elements, such as hydrogen and deuterium, chemical binding effects become significant below energies of 1 ev. Actually the scattering is proportional to the square of the reduced mass (6) of the neutron and the scatterer. If the hydrogen atom is free, the reduced mass $\mu \cong 0.5$. However, when hydrogen is bound in heavy molecules such as paraffin, the reduced mass will be $\mu \cong 1$. Consequently the ratio of the cross section of the free hydrogen atom to a rigidly bound one is approximately $(1/0.5)^2 = 4$. Or, in general, the cross section σ_b for a rigidly bound nucleus of mass A relative to the cross section σ_f of the same nucleus in a free state will be given by $\sigma_b = \sigma_f[(A + 1)/A]^2$.

When the energy of the neutron is considerably higher than the vibrational energy of the C—H bond in paraffin (*i.e.*, $E >> h\nu \approx 0.4$ ev), H may be separated from the molecule, and the

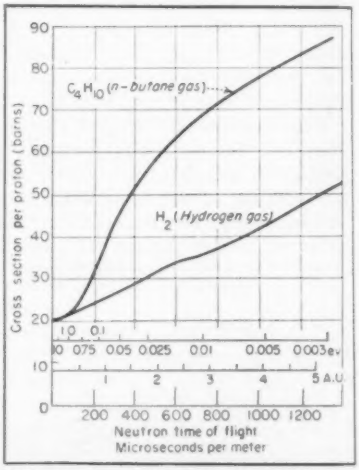


FIG. 4. Graph of neutron cross section of *n*-butane and hydrogen as function of neutron energy (approximate corrections have been made for translational motion)

cross section for hydrogen is what would be expected for free hydrogen atoms. At energies of the order of $h\nu$, however, the neutron can lose energy to the vibration of the hydrogen atom or other groups in the molecule. In this case the hydrogen atom is essentially bound, and the cross section increases to about four times that at the higher energies. Experiments show, in fact, that the cross section for hydrogen bound in a hydrocarbon molecule does increase from about 20 barns in the region of 10 to 1 ev to over 80 barns at energies of about 0.005 ev as shown in Fig. 4 (*10*).

These results indicate that thermal neutrons (0.026 ev) would be quite suitable for analyzing certain materials for hydrogen-containing compounds. Specific applications of thermal neutrons to such analysis will be considered later. Also, it appears that such cross-section curves plotted as a function of energy may give some useful information on the absorption and combination of hydrogen with metals.

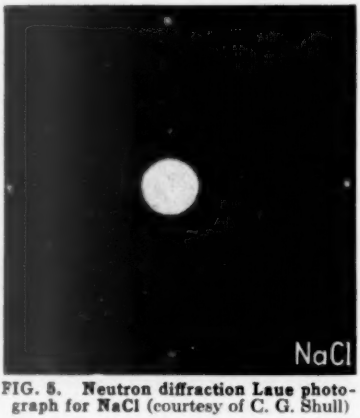


FIG. 5. Neutron diffraction Laue photograph for NaCl (courtesy of C. G. Shull)

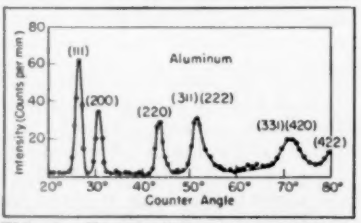


FIG. 6. Neutron diffraction powder pattern for aluminum (courtesy of C. G. Shull)

Diffraction. As the energy of the neutrons is decreased to the thermal region, where the associated wavelength is of the order of the distance between the atoms in crystals, diffraction effects are observed in accordance with the Bragg relation, $n\lambda = 2d \sin \theta$. When a heterogenous beam of thermal neutrons is passed through a single crystal, a Laue pattern can be obtained. Since neutrons do not affect a photographic emulsion sufficiently for direct photographic detection, it is necessary to use a neutron-absorbing material in the emulsion or to place a thin sheet of substance such as indium in front of the X-ray film. Radiations resulting from the neutron capture then produce the Laue spots (*4*) on the film as illustrated in Fig. 5. Monoenergetic neutrons may be used with powdered crystalline material to obtain powder diffraction patterns (*4*). In this case, a BF_3 counter can be used to measure the intensity as a function of the angle θ (Fig. 6). Transmission measurements on crystalline powders also show structure effects (*11*). Neutron diffraction patterns can be used either to determine crystal structures or to identify crystals as is done with X-ray diffraction patterns

In general, the equations for coherent nuclear scattering of neutrons are the same as the corresponding ones for X-ray diffraction but do not have the polarization factor. The principal differences are caused by the differences in cross sections for nuclear scattering of neutrons as compared to electronic scattering of X-rays. The decrease in intensity with respect to the angle θ is less for neutrons because their

scattering from the nuclei is essentially isotropic. Scattering from hydrogen or other light atoms does not differ greatly from that of other atoms. This makes it possible to determine the crystallographic position of hydrogen atoms in crystals with much greater ease than is possible with X-rays.

Differences between X-ray diffraction and neutron diffraction (*4*) also arise with respect to *diffuse scattering*. With neutrons, the different isotopes of an element may have different scattering amplitudes which must be combined algebraically before squaring to obtain the intensity. Also, the amplitudes of the parallel and antiparallel spins of the nuclei with respect to the neutron must be weighted for the two spin states. Here the situation is different for randomly oriented nuclear spins and for nuclear spins which have a definite orientation in a molecule, as is the case for ortho- and parahydrogen. Diffuse scattering for randomly oriented nuclei due to the spin effect will be zero when the scattering amplitudes for parallel and antiparallel spins are equal or for nuclei with zero spin. However, if they are equal in magnitude and opposite in sign, all crystal scattering will be diffuse and no Bragg maxima will be observed. It follows that a monoisotopic element with equal scattering amplitudes for the parallel and antiparallel spins will have no spin or isotope diffuse scattering, and the crystal scattering will all be in the Bragg peaks.

The *phase* of the total wave for the neutron and nucleus may be shifted relative to the incident wave during scattering. Positive and negative phase shifts correspond to scattering amplitudes of opposite sign, so that the scattered waves may be 180 deg out of phase with each other. If the relative phase of the scattered waves from two different elements of a crystal are 180 deg out of phase, marked effects will result in the intensity of the lines because of reflections from different planes. It has been found that H, Li, Ti, and Mn, for example, have negative scattering amplitudes, while most of the other elements studied have a positive scattering amplitude. This may also occur for two isotopes of an element. For example, Shull and Wollan (*4*) have shown that Li^6 and Li^7 have opposite scattering amplitudes.

When the energy of the neutrons is reduced to a value such that the wave length is equal to $2d$ for the first Bragg reflection, no coherent crystal scattering will occur. Neutrons of longer wavelength can then readily pass through the crystals. This effect has been used to obtain neutron beams of long wavelength by filtering through BeO (*12*). With such a filter, neutrons with wavelengths less than about 4.5 A.U. are scattered from the beam. The residual cross section for the longer wave lengths is then caused by absorption, inelastic molecular effects, crystal imperfections, spin, isotope and temperature effects. In addition, paramagnetic (*13*) and ferromagnetic substances have an additional effect caused by the spin-spin interaction of the unpaired electrons and the neutron.

From the preceding discussion it follows that the total cross section for transmission of crystals for slow neutrons will be given by:

$$\sigma_{total} = \sigma_a + \sigma_{el} + \sigma_{inel} + \sigma_{coh} + \sigma_D + \sigma_m + \cdots$$

in which the terms refer respectively to cross sections arising from absorption, elastic, inelastic, coherent Bragg, diffuse or incoherent effects already discussed, and magnetic effects. If the absorption is large it masks the other effects, and neutron diffraction for studying structure is not very

TABLE 2
Characteristics of Three Most Commonly Used Spectrometers

Type	*Useful Range (electron volts)*	*Resolution vs Energy (electron volts)*				*Neutron Source*
		0.025	1	10	100	
Mechanical spectrometer	0.001–1,000	~0.001	~0.1	~6	~30	Pile, RaBe
Crystal spectrometer	0.01–100	~0.001	~0.5	~10	..	Pile
Modulated cyclotron	0.001–10,000	~0.001	~0.1	~1	~20	Cyclotron, Linear accelerator

useful. In the energy range where coherent Bragg scattering occurs, most of the other effects are relatively smaller, and neutron diffraction will be useful for many problems in chemistry. It has already been applied to the structure of such substances as NaCl, NaBr, NaF, NaH, NaD, H_2O, D_2O, Al, diamond, MnO, BeO, LiF, alloys, gases, *etc.* Some of the other effects will also find interesting and useful applications to problems in chemistry.

Most of the interactions discussed here depend upon the energy or velocity of the neutrons. Consequently, for certain applications it is necessary to use a neutron spectrometer or some other means of selecting neutrons of a definite energy range.

Neutron Spectrometer

As will be discussed later, transmission measurements of a broad energy band of neutrons in the thermal region may be useful for determining certain elements in simple systems. In order to take advantage of the higher cross sections at the resonance velocity or of the changes in cross sections with neutron energy, however, it is necessary to have a means of determining the transmission of the sample at the desired neutron velocity. The characteristics of the three most commonly used spectrometers are listed in Table 2.

The three methods listed are all about equivalent in the thermal region (0.026 ev). At the higher energies, however, the modulated cyclotron has the best "resolution" in a usable beam or detection interval. The intensity of the beam at the energy of interest is an important factor in determining this resolution. Higher intensity neutron sources are more useful in this respect. In the thermal region, piles produce the greatest usable flux of neutrons: about 1×10^8 neutrons per cm^2 per sec at one meter from the thermal column compared to about 1×10^2 for a one-gram RaBe source, and 1×10^6 for a cyclotron. However, in the region from 1 to 100 ev the flux of neutrons obtainable from the cyclotron with suitable devices for slowing down the neutrons compares favorably with the present method of obtaining neutrons from a pile. For investigating broad high-energy resonances (*14*), a constant voltage generator such as a Van de Graaff machine can be used for the production of monoenergetic neutrons from 10 kev to 4 Mev.

Other Methods. Some information has been obtained about the variation in neutron cross sections with energy without using velocity selectors. One

method involves the use of filters combined with temperature control of the paraffin in which the neutrons are slowed down. By this means, the energy distribution of the neutrons can be varied to some extent (*15*). This method is not very useful because the beam is far from monochromatic and the energy distribution depends on a number of variables.

An indirect method of measuring resonance energies of an element employs the $1/v$ variation in the cross section of boron filters and the radioactivity of the element as a detector (*16*). The absorption coefficient k_a of boron filters is first measured for thermal neutrons and then for resonance energy neutrons. The latter value is determined from the radioactivation of a detector foil of the element, shielded from thermal neutrons by use of cadmium. Since the absorption by boron is proportional to $1/v$ or to $1/\sqrt{E}$, the energy E_r of the resonance absorption is given approximately by $E_r = E_a \times k_a^2/k_r^2$. This method gives reasonably good values for resonance energies where single levels are involved, but it does not have the flexibility or accuracy of the methods employing velocity selectors.

Resonance detectors (*9*) combined with suitable filters may at times be conveniently employed to measure transmissions of samples at the resonance energy of the detector. For example, the transmission of a substance for neutrons with an energy of 1.4 ev (the resonance absorption energy for indium) can be measured using indium foil surrounded by cadmium as a detector. The radioactivity induced in the foil with the sample in the beam, divided by the radioactivity induced in the foil with the sample out of the beam, gives the transmission of the sample at this energy. Other resonance detectors can then be used to measure the transmission at other energies.

Mechanical velocity selectors. The first experiments with a neutron velocity selector were made by Dunning, Pegram, Fink, Mitchell and Segrè (*17*), with a radium-beryllium source for neutrons. The velocity selector consisted of a system of fixed and rotating disks, each containing 50 neutron-opaque cadmium sectors. The system was arranged in such a way that, for a given speed of rotation and relative phase of the openings, only neutrons of a given velocity reached the detector. Because of limitations on the speed of rotation, measurements were possible only in the thermal region.

Another type of mechanical velocity selector has been devised by Fermi and his co-workers for use with the chain-reacting pile (*18*). A diagrammatic sketch of apparatus is given in Fig. 7. A rotating cylinder of alternate thin laminations of aluminum and cadmium is placed next to the graphite thermal neutron column. Neutrons can pass through the cylinder only when the direction of the layers is parallel to the beam. The mirror rotates with the cylinder, and the reflected light activates the photoelectric tube which in turn activates the BF_3 neutron counter. By adjusting the position of the mirror, the photoelectric tube and counter can be activated at time t after the neutrons have passed through the cylinder. Thus only those neutrons are counted whose velocity is equal to d/t. An absorber can then be placed in the beam and the transmission of neutrons through it for this velocity can be measured. The time t can then be changed and the transmission can be measured at other velocities. This method is useful to about 0.2 ev, where the resolution becomes poor because the speed at which the cylinder can be rotated is limited.

A new mechanical velocity selector for relatively high energy work has been developed by Selove (*19*) for use with

the Argonne pile. This spectrometer uses a combination of the Dunning and the Fermi velocity selectors. A shutter, which consists of a fixed, long, steel cylinder with sectors cut from it and a similar rotating cylinder, gives the bursts of neutrons. An electronic timing and coincidence system phases the detector with respect to the neutron bursts. By using small sectors (~ 0.010 in. wide), high rotational speeds, and a beam coming from that section of the pile which is relatively rich in high-energy neutrons, resolution and intensities comparable to those of modulated cyclotrons have been obtained recently. The further development of velocity selectors of this type is dependent on the construction of piles operating at a higher average neutron energy and with higher power. The disadvantages of an instrument of this type is that the shutter can handle only a limited energy range. To handle the complete spectrum, therefore, several different shutters have to be used.

Crystal spectrometer velocity selector (*4*). A selector of this type utilizes the wave properties of neutrons by methods similar to those used in X-ray spectroscopy. Figure 8 gives the general arrangement of the equipment.

Neutrons from a chain-reacting pile are collimated so that a parallel beam of neutrons hits the surface of a crystal such as LiF. Maxima in the diffraction pattern occur in such a way that the Bragg relation $n\lambda = (nh)/(mv) = 2d \sin \theta$ is satisfied. Here n is the order of the reflection, λ is the wavelength associated with a neutron moving with a velocity v, m is the mass of the neutron, h is Planck's constant, d is the distance between atomic planes and θ is the angle of incidence with the plane or angle of reflection. Neutrons of a given energy can be obtained by setting the crystal and detector at the appropriate angle with respect to the neutron beam. Thus, if the (100) planes of LiF in which $d = 2.005$ A.U. are set such that $\theta = 20$ deg, then the velocity of the neutrons impinging upon the crystal can be calculated in the following

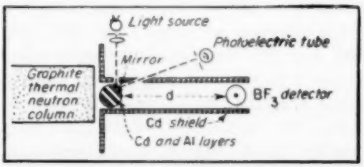


FIG. 7. Schematic diagram for a mechanical velocity selector

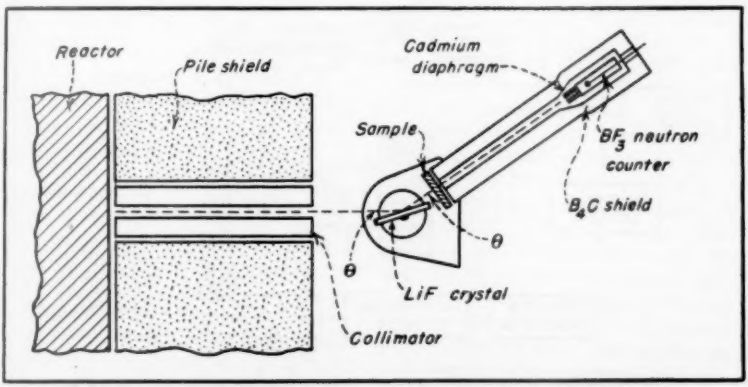


FIG. 8. Schematic diagram of a crystal spectrometer velocity selector

manner for a first-order reflection:

$$v = \frac{nh}{m2d \sin \theta}$$

$$= \frac{(1)(6.62 \times 10^{-27})}{(1.67 \times 10^{-24})(4.01 \times 10^{-8})(0.342)}$$

$$= 2.88 \times 10^{5} \text{ cm/sec}$$

which corresponds to an energy in electron volts of

$$E = \frac{\frac{1}{2}mv^2}{e} =$$

$$\frac{(0.5)(1.67 \times 10^{-24})(2.88 \times 10^{5})^2(300)}{4.80 \times 10^{-10}}$$

$$= 0.0430 \text{ ev}$$

or to a wavelength of $\lambda = h/(mv) = 1.38 \times 10^{-8}$ cm or 1.38 A.U.

To measure the transmission of a sample at this velocity, the intensity of the beam is measured, first without the sample present and then with the sample between the crystal and the detector. The angle of incidence, θ, can then be changed to obtain the transmission at other neutron energies from 0.01 to 100 ev. At the higher energies the angle of incidence is very small, and at lower energies the higher-order reflections interfere. One important advantage of the crystal spectrometer is that the beam is essentially monoenergetic. That is, the only neutrons which pass through the sample are those that have the energy given by the Bragg equation. Consequently, by measuring activation of the sample, the cross section of certain isotopes can be determined.

Time-of-flight velocity selector. Block diagrams showing the general principles of the modulated cyclotron velocity selector (*20*) are given in Figs. 9 and 10. By modulating the ion accelerating potential in the source of a cyclotron, short bursts of deuterons can be made to hit a beryllium target. This produces fast neutrons for short periods of τ μsec (variable from 2 to 1,024 μsec) in the Columbia University neutron spectrometer. After being slowed down in paraffin, they travel toward the detector placed at a distance d (6 meters) from the source. The neutrons arriving at the detector after t_1 μsec (except for a small correction for the time necessary to accelerate the deuterons and to slow down the neutrons) are counted for a period of τ' μsec. This period is usually the same as the time of the neutron burst τ.

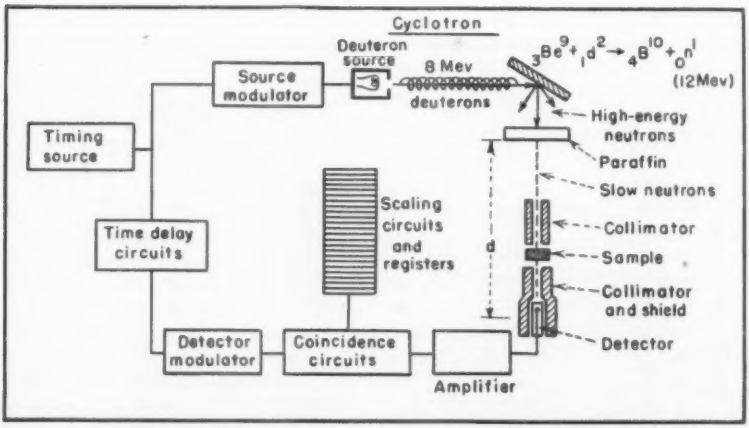


FIG. 9. Block diagram of time-of-flight velocity selector

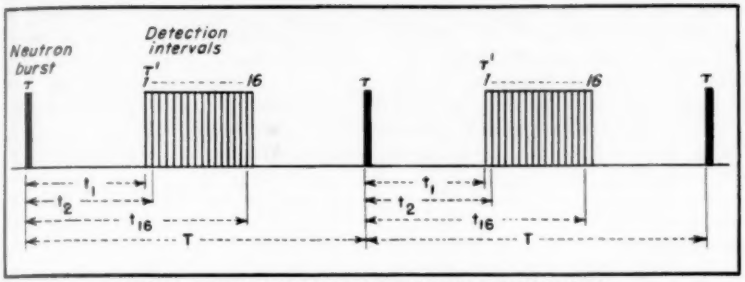


FIG. 10. Principle of the time-of-flight velocity selector

The time-of-flight of this group of neutrons is then t_1/d μsec per meter, or their velocity is d/t_1. At the end of this first detection interval, a second coincidence unit is turned on for τ' μsec to count the neutrons arriving after a time of t_2 μsec. In this way, a total of 16 scaling units count the neutrons arriving at the detector during each of the 16 successive detection intervals of τ' μsec each.

After a time T, which may be 1,024 μsec, for example, another burst of neutrons is produced, and the neutrons are again counted at each detection interval. The time between bursts can be adjusted in steps from 1,024 to 32,768 μsec and the detection may be started at any delay time t_1 after the start of the burst. Also both the duration of the burst τ and of the detection interval τ' can be varied from 2 to 1,024 μsec. With this system, the number of neutrons arriving at the detector as a function of time can be determined in any desired range of neutron energies from 0.001 to 10,000 ev. The resolution is approximately triangular and constant for a specified setting of the apparatus when measured on the time-of-flight basis.

The general arrangement of the cyclotron is shown diagrammatically in Fig. 11. Neutrons emerging from the paraffin source are collimated by thick shields of boron carbide. They

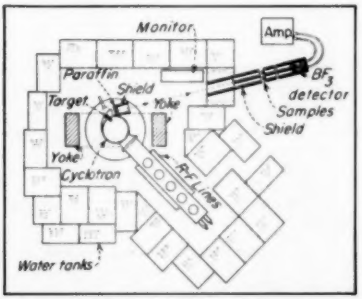


FIG. 11. Geometrical arrangement of cyclotron velocity selector, samples, and detector

then pass through the sample and into the detector, which consists of a proportional counter 10 cm long and 5.0 cm in diameter filled with 50 cm of BF_3 enriched in B^{10}. Actually two channels with associated detectors, circuits, and scaling units are provided. By alternating the container plus sample with an identical empty container between the two channels, duplicate determinations of the transmission can be obtained. An average of the values obtained in this way improves the accuracy of the transmission measurements by reducing the effects of fluctuations in the intensity of the neutron beam. The effects of fluctuations are also minimized by counting the neutrons arriving at the counters for equal amounts of total neutron production

rather than for equal intervals of time. A uranium fission chamber placed within the cyclotron enclosure is used for this purpose. Detailed discussion of the operation of the cyclotron velocity selector is given in the papers by Rainwater, Havens, Wu, Dunning and their associates (*20*).

With the aid of the modulated-cyclotron neutron spectrometer described in this section, it is possible to determine the resonance energy, the transmission at resonance, and the variation of cross section with neutron velocity. The application of these measurements to special problems in chemical analysis will be considered in the second paper in this series to appear in a later issue of NUCLEONICS.

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BIBLIOGRAPHY

1. J. Chadwick, *Proc. Royal Soc.* (London) **A136,** 692 (1932); **A142,** 1 (1933)
2. K. J. McCallum, NUCLEONICS **5,** No. 1, 11 (1949)
3. Symposium on Radiation Chemistry and Photochemistry. *J. Phys. Colloid Chem.* **52,** 437–611 (1948)
4. E. O. Wollan, C. G. Shull, NUCLEONICS **3,** No. 1, 8, No. 2, 17 (1948); *Phys. Rev.* **73,** 830 (1948); *Science* **108,** 69 (1948).
   Also E. O. Wollan, C. G. Shull, M. C. Marney, *Phys. Rev.* **73,** 527 (1948).
   Also W. H. Zinn, *Phys. Rev.* **71,** 725 (1947).
   Also E. Fermi, L. Marshall, *Phys. Rev.* **71,** 666 (1947)
5. N. Bohr, *Nature* **137,** 344, 352 (1936)
6. H. A. Bethe, R. F. Bacher, *Revs. Mod. Phys.* **8,** 83 (1936).
   Also H. A. Bethe, *Revs. Mod. Phys.* **9,** 69 (1937); "Elementary Nuclear Theory" (John Wiley & Sons, Inc., New York, 1947).
   Also M. S. Livingston, H. A. Bethe, *Revs. Mod. Phys.* **9,** 245 (1937)
7. G. T. Seaborg, I. Perlman, *Revs. Mod. Phys.* **20,** 585 (1948).
   Also W. E. Siri, "Isotopic Tracers and Nuclear Radiations with Applications to Biology and Medicine" (McGraw-Hill Book Co., Inc. New York, 1949)
8. G. Breit, E. P. Wigner, *Phys. Rev.* **49,** 519 (1936)
9. M. Goldhaber. Slow Neutron Reactions, Brookhaven Chemistry Conference No. 3 (July, 1949); *Abstract*, Washington, D. C. meeting, American Physical Society, (April, (1949).
   Also A. A. Yalow, M. Goldhaber, *Phys. Rev.* **68,** 99 (1945)
10. E. Melkonian, dissertation, Columbia University (1949)
11. M. D. Whitaker, H. G. Beyer, J. R. Dunning, *Phys. Rev.* **54,** 771 (1938).
    Also O. Halpern, M. Hamermesh, M. H. Johnson, *Phys. Rev.* **59.** 981 (1941)
12. E. Fermi, L. Marshall, *Phys. Rev.* **72,** 408 (1947)
13. I. Ruderman, W. W. Havens, T. I. Taylor, L. J. Rainwater, *Phys. Rev.* **75,** 895 (1949).
    Also O. Halpern, M. H. Johnson, *Phys. Rev.* **51,** 992 (1937); **52,** 52 (1937)
14. L. W. Seagandollar, H. H. Barschall, *Phys. Rev.* **72,** 439 (1947)
15. P. N. Powers, G. H. Fink, G. B. Pegram, *Phys. Rev.* **49,** 650 (1936).
    Also W. F. Libby, E. A. Long, *Phys. Rev.* **52,** 592 (1937)
16. H. H. Goldsmith, F. Rasetti, *Phys. Rev.* **50,** 328 (1936)
17. J. R. Dunning, G. B. Pegram, G. A. Fink, D. D. Mitchell, E. Segrè, *Phys. Rev.* **48,** 704 (1935)
18. E. Fermi, J. Marshall, L. Marshall, *Phys. Rev.* **72,** 193 (1947)
19. W. A. Selove, *Abstract*, Washington, D. C. meeting, American Physical Society (April, 1949)
20. L. Rainwater, W. W. Havens, C. S. Wu, J. R. Dunning, *Phys. Rev.* **71,** 65 (1947)

THE RESURGENCE of interest in iodine metabolism is but a reflection of the power of the new tools now available for biological and medical research. It represents, in a small way, the benefits which can be derived from the rapid advances that were made in nuclear physics in the past ten years.

——Leslie F. Nims, Chairman,
Biology Department, Brookhaven National Laboratory

Radiography with Cobalt-60

Concentrated sources of cobalt-60, suitable for use as a replacement for radium in industrial radiography of steel, have recently been made available from the Canadian nuclear reactor at Chalk River, Ontario. Graphs, from which exposure times for a range of thicknesses of steel and for different types of films can be determined, are presented, along with other information useful in handling and shipping of this isotope

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Ottawa, Ontario, Canada

THE USE of the gamma rays of radium in the radiography of castings and welds of steel is well established. During the war much use was made of radiography as a test of quality and as a means of improving foundry methods and welding techniques. Because of its utility in helping foundries and welding shops to increase the skill of their workmen, to develop improved methods, and to raise the quality of their products, many of the firms that used gamma radiography in wartime would like to continue to use it now. However, the high initial cost of even a small quantity of radium, and the long exposures required with consequent high overhead, have tended to deter them from doing so. A gamma-ray source less costly than radium and available in units of greater activity so that shorter exposure times would be possible, is what is needed. Such a source is now available in cobalt-60.

Even before the war, a large number of radioactive isotopes, some of which were gamma emitters, had been produced. With the methods then available for the production of radioisotopes —the cyclotron, the electrostatic accelerator and the radium-beryllium neutron source—the amounts of any isotope which could be produced were extremely small, and the activities of even short-lived isotopes were of the order of microcuries or a few millicuries, far less than the least amount which would be useful for radiography. In addition, the cost of such isotopes as were produced, when expressed in dollars per millicurie, was far higher than the cost of radium. Not until the nuclear reactor was developed, could large amounts of an isotope be produced at low cost.

Although large quantities of radioisotopes can be produced with a nuclear reactor, either by fission or by neutron irradiation, the number produced which can be used for gamma-ray radiography to replace radium is severely limited by the criteria which must be met. These criteria are (*a*) the energy of the gamma rays, (*b*) the half-life of the isotope, (*c*) the specific activity of the isotope, (*d*) the ease of production, and (*e*) the producible quantity. Each will be dealt with separately here.

Characteristics of Good Source

The energy of the gamma rays from a good source must be between one and three Mev so that the penetration

or the rate of change of intensity with thickness of material will be similar to that of radium. The gamma rays from radium that are useful in the radiography of steel lie between 200 kev and about 2.4 Mev. The half-value layer in steel from one to four inches thick for this composite radiation is about 1.0 inches, and voids about 2% of the thickness of the steel can be seen. If the radiation is too penetrating, small defects will not cause sufficient change in intensity to produce a visible change in density on the radiograph and will not be seen. If the radiation is less penetrating and the half-value layer is small, small defects will clearly be seen but the attenuation will be so rapid that the thicknesses of steel which can be examined with a reasonable exposure time will be limited.

The half-life, while it need not be as long as that of radium, must be sufficiently long that the gamma-ray intensity does not change appreciably during the exposure period and, in fact, should be such that the source strength does not change appreciably from week to week. A comparison of radon, which has the short half-life of 3.83 days, with long-lived radium illustrates the difficulties that arise in planning exposures using gamma emitters of short half-life. An exposure which, if made with 100 mg of radium would require 9.0 hours, when made with radon of initial strength 100 millicuries (same initial gamma-ray intensity as the radium), will require 9.3 hours because of the decay of the radon during exposure. If the geometry is changed so that the radium exposure time is 36 hours, the corresponding radon exposure time is 42 hours. A second similar exposure using radon, started when the first one is finished, would require 57.5 hours since the initial strength of the radon is 73 mc instead of the original 100 mc which existed before decay.

Since the source size affects the sharpness of the shadow formed on film, the activity of the source per cubic millimeter, that is, the intensity of gamma radiation emitted per cubic millimeter of isotope, must be at least equal to that for radium. A point source of radiation would be best of all; the closer the isotope approaches this the better. Specific activity is usually stated in mc per mg or mc per gm. However, for radiography, the important characteristic is the gamma-ray activity per cubic millimeter, and, for an isotope which is to replace radium, this can be measured in terms of the number of milligrams of radium to which each cubic millimeter of isotope is equivalent. The specific activity for radium is about 2 mg radium per cubic millimeter or for compressed sources is about 3 mg of radium per cubic millimeter. Thus, an isotope should be equivalent to 2 or 3 mg of radium per cubic millimeter or, if possible, more.

The cost of production must be sufficiently low that the price of the isotope to the user is less than that of radium. Radium at present sells for about $20 per mg. If half of this cost is written off over the first 10 years, the cost per year is about $1 per mg. Rented radium costs about $2.50 to $3 per mg per year.

Isotopes may be prepared either by separation from fission products or by irradiation in a nuclear reactor or pile. The separation of gamma emitters from the fission products is a difficult and lengthy process requiring elaborate chemical equipment and complicated operations. Irradiation in the pile seems to be a more probable immediate source of many isotopes.

The cost of producing an isotope by neutron irradiation is determined by its half-life, its neutron cross section, and the physical handling required. Solid materials are easier to handle

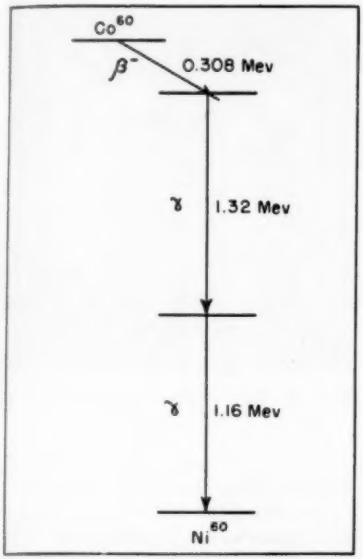


FIG. 1. Decay scheme for Co^{60}

than liquid ones. Half-lives longer than 10 or 20 years require long irradiations to get adequate specific activity. Certain elements may be undesirable because they cannot be prepared in a suitable form or because the irradiation produces undesired reactions. The preparation should not require complex chemical separation.

To be useful, a radiographic source should be equivalent to at least 300 mg of radium. A better minimum size would be one equivalent to 500 mg of radium. With either of these sources, radiographs of an inch of steel can be made with exposures of six hours, using a reasonable distance and geometry and a fast film, or with overnight exposures of 16 or 17 hours using a slower film or a larger distance. With much larger sources, equivalent to 1.0 or 1.5 gm of radium, the distance can be increased, improving the geometry and, in the case of castings radiographed in a circle surrounding the source, increasing the radius of the circle and hence the number of castings which can be examined in a given time. Alternatively, with large sources, a slower speed film can be used, thus enhancing the contrast, improving the appearance, and increasing the sensitivity of the radiograph. An isotope, to replace radium, should be obtainable in units with gamma radiation equivalent to 0.5 to 2.0 or 3.0 gm radium. It should also be possible to produce many such sources quickly and cheaply.

As stated earlier, Co^{60} meets the above requirements quite well and can be readily prepared in a nuclear reactor from the normal cobalt, Co^{59}.

Physical Properties of Co^{60}

Cobalt-60 is prepared by the slow neutron bombardment of pure cobalt. The reaction is

$$_{27}Co^{59} + {}_{0}n^{1} \rightarrow {}_{27}Co^{60}$$

$$_{27}Co^{60} \xrightarrow{\beta,\gamma,\gamma} {}_{28}Ni^{60}$$

A decay scheme for the 5.3-y Co^{60} has been given by Evans (*1*), and is reproduced in Fig. 1.

Two gamma rays are emitted in cascade and recent figures for the energies of these are 1.17 and 1.33 Mev (*11*). These values replace the earlier ones of 1.16 and 1.32 Mev (*2, 3*) and of 1.10 and 1.30 Mev (*4*).

The half-life of Co^{60} is usually taken as 5.3 years, as originally determined by Livingood and Seaborg (*5*). This is sufficiently long to be quite convenient. A decay of 5% requires about 5 months, so that a recalculation of the source strength each 5 or 6 months will be sufficiently accurate for radiographic purposes.

Cobalt sources have been prepared with gamma activities corresponding to 10 mg radium per cubic mm. Much higher specific activities, equivalent to 25 mg radium per cubic mm, are possible with a larger, but still practical, irradiation. These specific activities

compare very favorably with that of radium, since a Co^{60} source can have a diameter less than half as great as that of the best available radium source of the same gamma-ray strength.

At present, sources having gamma radiation equivalent to that from 2.4 gm of radium consist of a cylinder of cobalt 6.5 mm in diameter by 6.5 mm high. Cylinders of pure cobalt are placed in a prepared block of aluminum, which is welded, machined, and sealed into an irradiation can, and irradiated in the reactor. A photograph of one of the first sources and of the later design now adopted is given in Fig. 2. The various holes in the aluminum cylinder are intended to accommodate handling devices.

FIG. 2. Co^{60} sources in aluminum protective containers

Measurement of Source

The strength of radium sources for radiography is stated in milligrams of radium or in millicuries; for radium, the two units are interchangeable.* With Co^{60} neither unit is suitable. The milligrams of cobalt present do not measure the strength of the source since the activity per milligram is not a natural constant as it is for radium, but is dependent on the time and intensity of neutron irradiation. The millicurie, if defined as a rate of disintegration, 3.70×10^7 disintegrations per second, or the rutherford, 10^6 disintegrations per second, might serve as a measure of Co^{60} gamma-ray activity, but for large sources of the order of one curie, it is difficult to determine the disintegration rate accurately.

A unit of radiation intensity such as the milliroentgen per hour at a meter is difficult to measure in any absolute sense for penetrating gamma radiations. It could be measured by comparison with a radium source, but this would have little or no advantage over a direct comparison of the cobalt source with a radium source either by photographic or ionization methods.

Determination of the strength of a Co^{60} source by comparing it with radium could be done by comparing the effect of the two sources on X-ray film exposed with similar geometry. The reciprocal of the time required to reach a definite density would be a measure of the source strength. The photographic method, however, is rather inaccurate in that it is subject to variations in the film used and in the processing conditions. It is hard to get results reproducible to better than 5%.

Different ionization chambers may show different ratios between a cobalt and radium source since the ionization within the chamber is partly dependent on the thickness and material of the chamber wall and on the spectrum of the radiation. A variation in the thickness or in the material of the wall may change slightly the composition of the spectrum and hence the response of the chamber. If the wall thickness is made sufficiently great that soft components of the radium spectrum are absorbed, comparison is easy.

For our measurements, the standard ionization chamber used for radium

* See p. 49 for new recommendation for this relationship.

measurement, with an outer wall of 0.5 cm of lead lined with 0.5 cm of aluminum, was available and appeared to be suitable. Each cobalt source was compared with a radium source of about 250 mg radium content. The strength of the cobalt source was then expressed in terms of the number of milligrams of radium which would have the same gamma-ray intensity when measured on this particular chamber. Although the unit, milligrams radium equivalent, is a rather awkward one, it appears to be the most practical one to use at this time; conversion can be made later to any other unit which appears more desirable.

Preparation of Exposure Graphs

One of the major problems in radiography is the selection, for a given source, and for a particular casting, of that combination of exposure time, source-to-film distance and type of film, which will result in a satisfactory radiograph. A satisfactory radiograph must have had an exposure such that adequate sensitivity is achieved in the low density areas which correspond to thick sections of the object, as well as in the high density areas under the thin sections. Also, these high density areas must still not be too opaque to be examined with the available illuminators.

In arranging the exposure, some of the limitations in choice of time, distance, and film become apparent. Exposure times must be not longer than 7 or 8 hours for an exposure during the working day and must be between 15 and 18 hours for an overnight exposure. The source-to-film distance has a lower limit which is set by the thickness or the shape of the object to be radiographed, or by the sensitivity desired. Almost any source-to-film distance greater than this lower limit can be used with advantage since as the distance increases the rays become more nearly parallel and the finite size of the source becomes less disadvantageous.

Films are available in a number of speeds, each with its characteristic grain size, latitude, and contrast. Graphs showing the relationship between these factors greatly facilitate the choice of a suitable combination of them.

The graphs presented here (Figs. 3–9) are similar to those used earlier for radium radiography of steel (*6*). These graphs cover only exposures with Co^{60} for steel, and a separate graph is used for each type of film.

In these graphs the thickness of steel is the abscissa; a linear scale is used extending from 0 to 3.5 inches. The ordinate is "exposure factor" where this is equal to

$$\frac{\text{mg Ra equivalent} \times \text{minutes of exposure}}{(\text{source-to-film distance, in inches})^2}$$

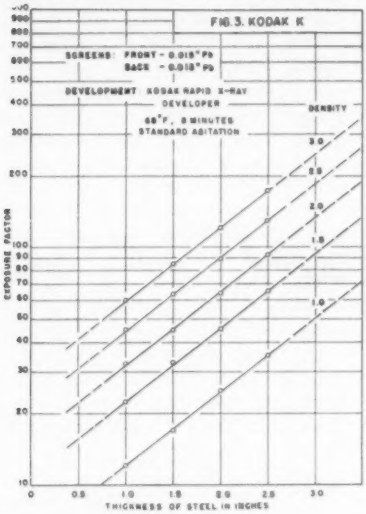
The scale for the exposure-factor axis is logarithmic. Two cycles, from 10 to 1,000, are used.

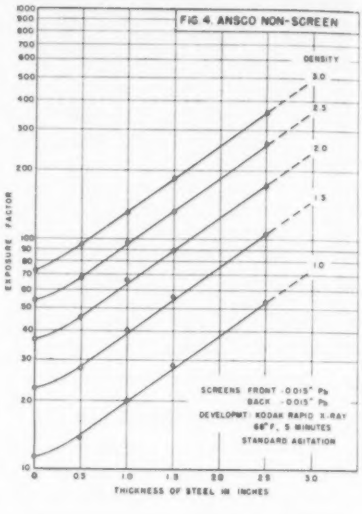
On each graph, lines showing the relationship between steel thickness and exposure factor are obtained by plotting, for three or more steel thicknesses, the exposure factors corresponding to densities of 1.0, 1.5, 2.0, 2.5 and 3.0, and by linking the points of equal density with straight lines.

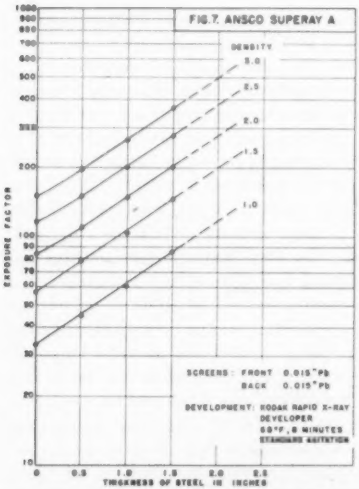
For each film type and for each thickness of steel, a series of exposures was made. The films were carefully developed, using a standardized procedure, and washed and dried. The densities of the films in each series were then measured and plotted against exposure factor. From these curves the exposure factors for the densities 1.0, 1.5, *etc.*, mentioned previously, were read.

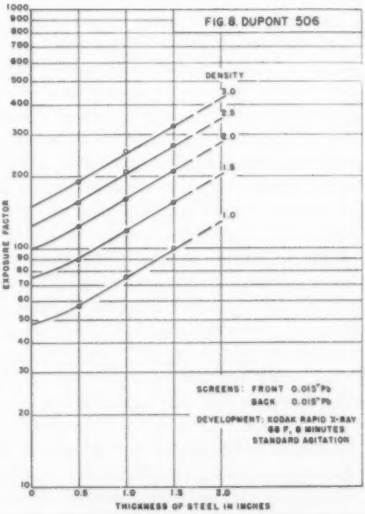
Each series of exposures consisted of six films loaded into cardboard cassettes, each held vertically by a light plywood frame, and each having one or more pieces of steel plate

EXPOSURE GRAPHS FOR COBALT-60

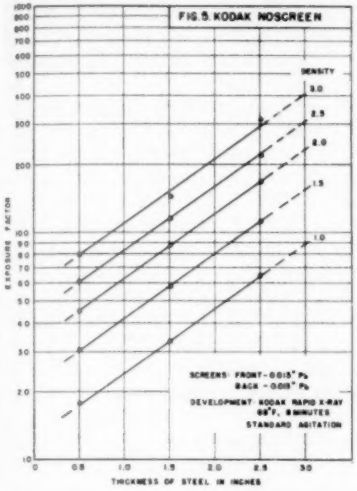


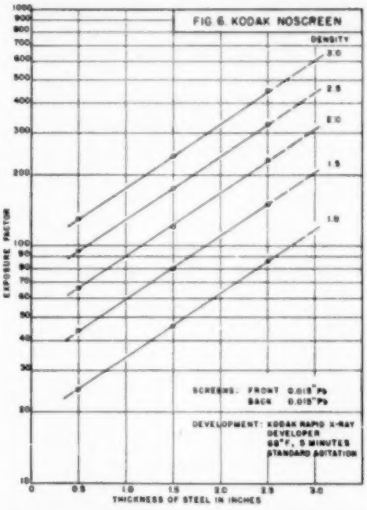


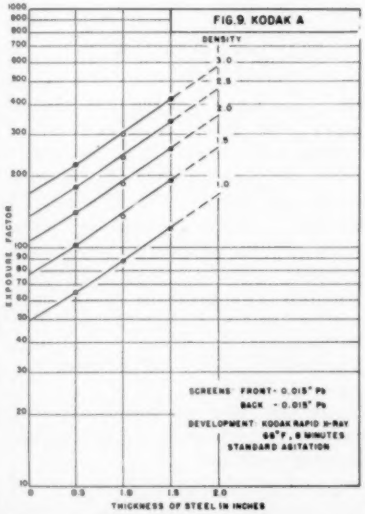




standing directly in front of it. These six films were arranged on a table top or table tops along radii extending outward from the source. The source was mounted on a light aluminum stand of a height such that the center of the source was at the height of the center of the films. The film holders were arranged around the circumference of a circle of radius of 20 inches







or more, or were arranged at a series of distances from the source. In the first case, different exposures were obtained by removing the films at different times, while in the second case all films were removed at the same time. The first arrangement was suitable for short exposures during the day, and the second was suitable for long or overnight exposures. The same densities were obtained for the same exposure factors with the two methods. The different exposure factors were chosen to produce densities in the range from just less than 1.0 to just under 3.0.

The lead foil intensifying screens used on each side of each film were 0.015 inches in thickness. This was chosen as being about the optimum thickness for the range of steel thicknesses used.

Development of the exposed films was done in a standardized way so that all would receive the same treatment. The temperature was maintained at 68° F and the development time was eight minutes or five minutes. A horizontal agitation of the film in the developer, using the method described elsewhere (*6*), was given at the end of the first, third and fifth

minutes, for the eight-minute development, and at the end of the first and third minutes in the five-minute development.

Two similarly exposed sets of films of each of two types, Kodak "Noscreen" and Agfa "Superay A," were given eight-minute and five-minute development. From the comparison of these, and of other sets made with radium exposures and given the two development periods, it appeared that a given density can be obtained with eight-minute development by using 0.7 times the exposure required to get that density with five-minute development. In general, for radiography with radium or Co^{60}, the longer development should be used since with it the exposure time can be reduced considerably.

All densities were measured with an Ansco-Sweet, Model 11, photoelectric densitometer. Any other densitometer could have been used; there would have been slight variations in the results since the different densitometers measure slightly different proportions of specular and diffuse density. If a suitable densitometer had been available, measurements of density up to 4.0 to 5.0 would have been useful. With very bright illuminators such densities can be read, and, for the non-screen types of films used for gamma-ray radiography, the contrast and sensitivity improves as the density increases.

Use of Graphs

The graphs presented in Figs. 3–9 give data for Kodak "K," "Noscreen" and "A" films, for Ansco "Non-screen," and "Superay A" films, and for Dupont "506" film.

The way in which the graphs are used could perhaps best be made clear by examples. Let us assume that a steel weld 1¼ inches thick is to be examined, using a source of

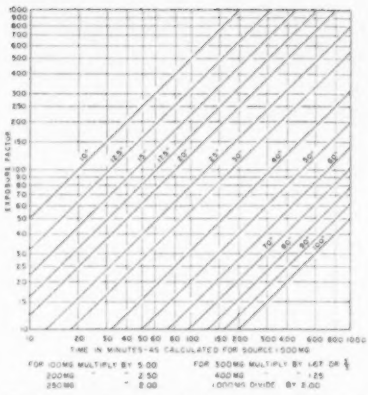

EXPOSURE FACTOR
TIME IN MINUTES-AS CALCULATED FOR SOURCE-1 500 MG
FOR 100MG MULTIPLY BY 5.00
200MG " 2.50
250MG " 2.00
FOR 500MG MULTIPLY BY 1.67 OR ⅔
400MG " .125
(200 MG DIVIDE BY 2.00

FIG. 10. Graph relating time, distance and exposure factor

500 mg radium equivalent. If type "K" film is chosen and a density of 1.5 is considered to be adequate, an exposure factor of about 27 is required (Fig. 3), *i.e.*:

$$\frac{500 \times \text{time in minutes}}{(\text{distance})^2} = 27$$

The usual X-ray film has a maximum length of 17 inches, and, as a rough working rule, the distance from the source to the center of the film should be at least equal to the diagonal of the film. For this example, 18 inches would be considered the minimum distance. Then

$$27 = \frac{500t}{324}$$

or $$t = \frac{27 \times 324}{500} = 17.5 \text{ minutes}$$

If, on the other hand, the exposure time were chosen as 2 hours, then the distance would be

$$27 = \frac{500 \times 120}{d^2}$$

or $$d^2 = 2{,}200$$

$$d = 47 \text{ inches, approximately}$$

In this latter case, because of the greater source-to-film distance, there will be less distortion at the ends of

the radiograph than there would be with the 18-inch distance. If better sensitivity is desired, a slower film with finer grain and higher contrast, such as Dupont "506," may be used. In this case, for the same density and with the 18-inch source-to-film distance, the time required is about 90 minutes.

The calculations of time or distance, once the exposure factor has been determined has been somewhat facilitated by a graph such as shown in Fig. 10, in which, having fixed any two of the three quantities, time, distance and exposure factor, the third can be obtained from the graph. This graph assumes a source strength of 500 mg radium equivalent. Other source strengths can be used by multiplying the time by an appropriate factor, *e.g.*, by 2.5 for a source strength of 200 mg radium equivalent.

There are other ways of expressing some or all of the data contained in the above graphs. A type of graph

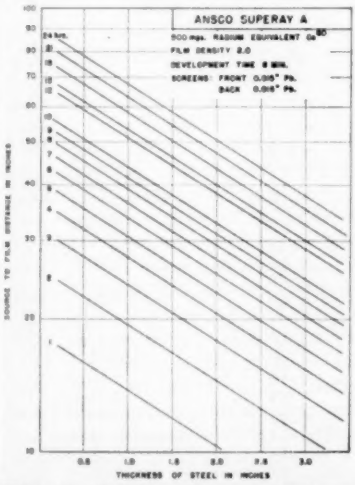

ANSCO SUPERAY A
500 mgs. RADIUM EQUIVALENT Co60
FILM DENSITY 2.0
DEVELOPMENT TIME 8 MIN.
SCREENS: FRONT 0.005" Pb.
BACK 0.010" Pb.
SOURCE TO FILM DISTANCE IN INCHES
THICKNESS OF STEEL IN INCHES

FIG. 11. Relation between exposure time, source-to-film distance and steel thickness for Ansco "Superay A" film at density 2.0

designed for a particular source and a particular film density is given in Fig. 11. Similar graphs can be prepared for other films.

Special Techniques

There are two special techniques which, while fairly common in gamma-ray radiography, should perhaps be mentioned here since both can be used more readily with Co^{60} than with radium. One of these is the use of high density to secure sensitivity, and the other is the use of two films in the same cassette or exposure holder to cover a wide range of thicknesses in one exposure.

The non-screen types of films normally used for gamma-ray radiography, for which graphs have been given here, unlike those used with fluorescent screens in X-ray radiography, can be exposed with advantage to densities of 4.0 or 5.0 or higher. They show constant or improving subject contrast as the density increases. The screen-type films tend to reach their maximum density at not much over 3.0, and exposures which produce densities much greater than 1.5 or 2.0 do not produce any improvement in the quality of the image. On the ordinary illuminator, densities above 3.0 cannot be examined, but with special high intensity illuminators which can be built or purchased, and with stripping techniques, densities up to 4.0 or 5.0 can be examined, and the latitude of thickness which can be seen in one radiograph with a given minimum sensitivity can be correspondingly increased. This question has been discussed by L. W. Ball (7). Useful though it might be, this technique has been, for radium, applicable only to thin sections since, for thicker sections and the usual radium capsules, the exposure time becomes excessive. With Co^{60} sources, which can be obtained many times stronger than radium

sources, exposures adequate for thick material can now be made in a reasonable time.

The second technique is the use of two films of unequal speed in the same cassette as a means of extending the range of thicknesses which can be measured with one exposure. For example, by using Kodak "Noscreen" and Ansco "Superay A" films, with an exposure factor of 100, steel thicknesses up to 3.0 inches can easily be examined, whereas with an exposure factor of 200, using an intense illuminator, steel thicknesses of 0.5 inches to greater than 4.0 inches can be seen. Other suitable combinations of films can be found from the exposure graphs.

Sensitivity

Because of the difference in the gamma-ray spectra of radium and Co^{60}, it seemed desirable to determine whether or not the 2% sensitivity required by the ASME Boiler Code could be obtained with Co^{60} under the same conditions as it could be obtained with radium. The results of a series of tests and comparisons were:

1. Co^{60} gamma rays gave slightly less sensitivity than could be obtained with radium.

2. The sensitivity of 2% as measured by the visibility of a 2% penetrometer, Boiler Code pattern, on 1¼ inches of steel, could be obtained with the finely grained slow speed films, such as Dupont "506" and Kodak "A," at densities of 2.0 or higher, but could not be obtained with Kodak Type "K," "Noscreen" or Ansco "Non-screen" films. A sensitivity of 3% could be obtained with these films at densities of 1.5 and higher.

Since sensitivity is dependent, in part, on the geometry and the size of the source and is difficult to measure precisely, it should always be tested directly. However, it would appear to be safe to say that, with good exposure and development technique, 2% sensitivity can be obtained using fine-grained films exposed to a density greater than 2.0.

Compensation for Decay

The half-life of Co^{60} is relatively short, 5.3 years, so that it cannot be considered as a source of constant strength in the same way that radium can; the source strength must be adjusted from time to time to allow for its decay. The graph of Fig. 12 shows the decay of Co^{60} over periods of six months and of six years, and Table 1 shows the decay for intervals of three months up to five years, calculated from

$$I = I_0 e^{-\lambda t}$$

or

$$I = I_0 e^{-(0.0109)t}$$

where t is in months and I_0 is the value at the beginning of the period.

TABLE 1
Decay of Co^{60}

Time in Months	*Decay Factor*
3	0.9678
6	0.9366
9	0.9066
12	0.8772
15	0.8491
18	0.8220
21	0.7953
24	0.7695
27	0.7453
30	0.7211
33	0.6977
36	0.6757
39	0.6538
42	0.6325
45	0.6126
48	0.5927
51	0.5735
54	0.5549
57	0.5374
60	0.5200
63	0.5036
63.6	0.5000

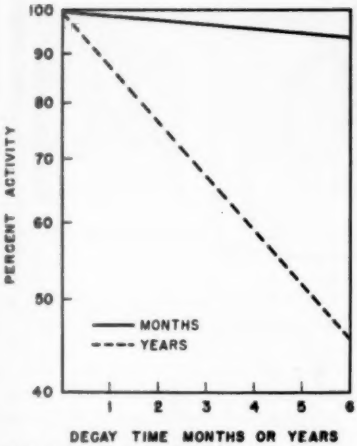


FIG. 12. Decay of Co^{60}

For industrial radiography the correction of the source strength at intervals of six months is probably sufficiently accurate, particularly if the average value over each six-month period is used for the whole of that period, *i.e.*, $(I_0 \times 0.968)$.

Handling and Storage of Co^{60}

The precautions necessary in handling Co^{60} are essentially the same as those required with radium. Since large sources will be more common with Co^{60} than with radium and may be used by persons who are less familiar with the safety requirements than has been the case with radium, the necessary precautions will be outlined.

Cobalt-60 emits gamma rays continuously and, for sources of the size used for radiography, the amount of radiation to which a person using the source is exposed can easily exceed the daily permissible value, unless the protection factors of time, distance and absorbing material are skillfully combined.

In this laboratory, the accepted daily permissible dose is 50 milliroentgens per day. A source of strength

FIG. 13. Tools for handling radioactive sources

1,000 mg radium equivalent has been determined here to produce 730 mr in one hour at a distance of one meter from the source, so that at this distance the daily permissible dose will be reached in about four minutes. The need for speed in transferring the source from its shipping container to the position for radiography is self-evident.

Since the variation of intensity with distance is governed by the inverse square law, long-handled tools are an efficient way of reducing the exposure of the operator. Three designs used in this laboratory are illustrated in Fig. 13. Each of these designs is about one meter in length.

The first one consists of a tube and end cup, with a spring-retracted, central rod, threaded at the end to correspond to the central hole in the ends of the source. Pins projecting from the flat bottom of the cup engage the holes in the top of the aluminum source. The central rod can be pushed forward and rotated so that the thread draws it into the central hole of the source. The source is then held by spring tension against the flat bottom of the cup and becomes part of a rigid tube and source assembly. This is a convenient method of mounting the source for radiography.

The second is a simple hook and is used with an eyelet screwed into one end of the aluminum source cylinder.

The third is a long-handled pistol-grip tongs; the movable finger is closed by the pressure of the spring-loaded central rod and is opened by a

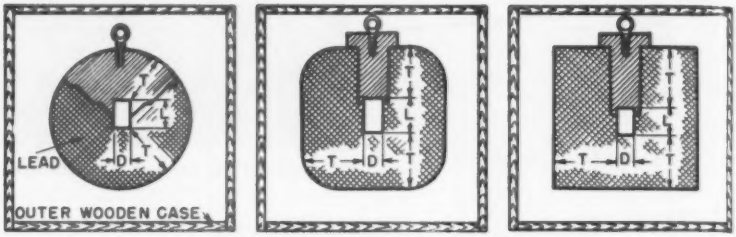


FIG. 14. Storage containers for Co^{60}

flat coil spring, when the rod is withdrawn, by pulling the trigger-like stem back towards the grip.

When not in use, the source must be kept in a storage container. Lead, because of its high absorption, is the most practical material for such a container. Several designs have been used and cross sections of three of these are given in Fig. 14. The most important characteristic is the thickness T of the lead wall. This thickness can be determined from the source strength and the attenuation desired. For shipping containers the requirements are that the radiation be so attenuated that the intensity on any part of the surface of the container does not exceed 200 mr per hour, and the intensity at one meter from the source is not greater than 10 mr per hour. Since the storage container is usually used as the shipping container, it should be made to conform with these requirements. Assuming that the box is a cube of 18-inch side with the lead container at the center, Table 2 gives thicknesses, T, for the lead cylinder for various sizes of sources.

TABLE 2

Storage Container Thicknesses

Source Size (mg Ra eq.)	*Lead Thickness (cm)*
100	4.0
500	6.8
1,000	7.9

An attenuation curve for lead in the form of cylinders with the source at the center determined here recently by L. F. Cudney and the author is given in Fig. 15.

In Table 2, the largest source listed is 1,000 mg radium equivalent. For sources larger than this the usual handling methods become increasingly impractical and it is then necessary to design storage containers which can be opened for exposure purposes to allow a cone of radiation or a circle of radiation to emerge or which have a remotely controlled mechanism for lifting the source from the container and returning it to the container.

With Co^{60} sources there is no possibility of contamination through breakage of the containing capsule and there is nothing equivalent to the leakage of radon which can sometimes occur from a radium capsule since the decay of cobalt results in a stable solid rather than a radioactive gas.

Some means of recording exposure to radiation resulting from use of sources equivalent to 500 mg of radium, or larger, is necessary. Either film badges or pocket electroscopes are satisfactory. Film badges should be developed and reported weekly. There are several commercial services available, and there have been several papers on the use of film badges

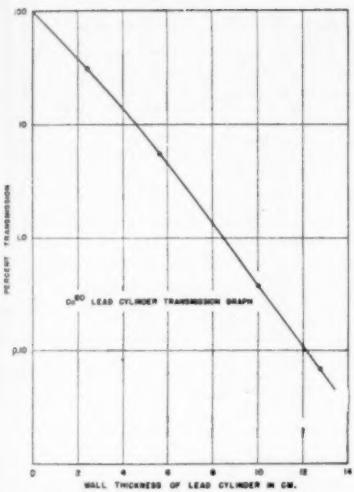


FIG. 15. Attenuation of gamma-rays from Co^{60} by lead cylinders

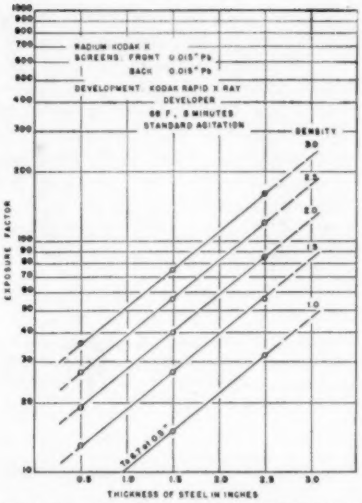


FIG. 16. Exposure graph for Kodak "K" film when used with radium

(*8*, *9*, *10*). For very large sources, 1,500 mg radium equivalent or larger, it would seem worthwhile to use both film badges and pocket electroscopes. The Lauritsen-type pocket chambers permit rapid determination of the exposures received in a single operation.

Comparison with Radium

An exposure graph similar to the ones given on pgs. 24 and 25 for Co^{60} is given in Fig. 16 for radium when used with Kodak "K" film.

It will be noted that the speeds are not the same, that is, for one inch of steel and density 1.5, an exposure factor of 19 is required with radium and of 22 with Co^{60}, even though the source strength in the case of cobalt is expressed in terms of milligrams radium equivalent. This is believed to be due to the different response of the film to the different spectra of primary and scattered radiation produced in the two cases.

The half-value layer, as measured by the thickness of steel, which corresponds to doubling the exposure factor along one of the lines of constant density, is about 1.0 inches for radium and about 0.95 inches in the case of cobalt. This difference is very small, and the exact value varies slightly with the particular film graph used, partly because of experimental error, and partly because of slight differences in the response of the different films to the blend of primary and secondary radiation.

The contrast of the film in the two cases as measured by the separation, parallel to the exposure factor axis, of lines of equal density, is about equal.

The cost of the two sources shows the greatest discrepancy. At present the cost of radium is about $20 per milligram. The price proposed by the U. S. AEC for Co^{60} in its latest price list is far below the figure given here.

From the foregoing, it is apparent

that Co^{60} can be substituted readily for radium in industrial radiography It has several advantages: low cost, high activity, and small source size—and a few disadvantages: it does not have quite as good sensitivity as radium and its decay is rapid, requiring frequent correction of the figure for source strength and eventually replacement of the source when the exposure times become inconveniently long.

* * *

I would like to acknowledge gratefully the assistance of Miss E. Ferguson and Mr. K. J. Parry in preparing the data embodied in the tables and graphs presented.

BIBLIOGRAPHY

1. R. D. Evans. NUCLEONICS **1**, No. 2, 32 (1947)
2. E. N. Jensen, L. J. Laslett, W. W. Pratt. *Phys. Rev.* **75**, 458 (1949)
3. L. C. Miller, L. F. Curtiss. *J. Research Nat. Bur. Standards* **38**, 359 (1947)
4. M. Deutsch, L. G. Elliott, A. Roberts *Phys. Rev.* **68**, 193 (1945)
5. J. J. Livingood, G. T. Seaborg. *Phys. Rev.* **60**, 913 (1941)
6. A. Morrison, E. M. Nodwell. *ASTM Bull.* **No. 127**, 25 (March, 1944)
7. L. W. Ball. *ASTM Bull.* **No. 116**, 29 (May, 1942)
8. H. O. Whipple, C. S. Hornberger, J. G. Hoffman, J. F. Nolan. *Am. J. Roentgenol. Radium Therapy* **60**, 175 (1948)
9. R. F. Cowling, C. K. Spalding. *Radiology* **52**, 423 (1948)
10. A. Morrison. NUCLEONICS **3**, No. 3, 46 (1948)
11. E. N. Jensen, L. J. Laslett, W. W. Pratt, *Phys. Rev.* **76**, 430 (1949)

THE ACCOUNTANT vs THE ATOM

or

PINNING A $-SIGN ON THE TAIL OF AN ATOM*

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AS YOU KNOW, the atom is an elusive little something, which is defined as the smallest unit of which a chemical element is built. Atoms used to be considered fundamental, indestructible things in nature.

In atomic energy work, we are concerned basically with high-energy radiation. High-energy radiation comes from the core, the nucleus, of the atom.

Once people thought that the atom was the smallest bit of matter, but now they know that the atom itself is made up of outer shells of electrons, which revolve about the nucleus of the atom, and that the nucleus too, is made up of particles, mainly protons and neutrons. Physicists now subdivide the atom into fifteen fundamental particles, and wonder if they have reached the ultimate in foundation stones. These particles are held together by a store of energy. When this energy is set free by splitting the atom, or when the particles are jarred loose from their normal orbits, high-energy radiation is released.

In 1946, our Congress decided that the unprecedented forces of atomic

* From a speech delivered before the Cedar Rapids, Iowa, chapter of the National Association of Cost Accountants, Oct. 18, 1949.

energy promised much for the future welfare of man, and that a civilian agency should be established to control the development and utilization of these forces. On January 1, 1947, the Atomic Energy Commission came into existence and took over the atomic energy program. The Commission was charged by law with the exclusive control of materials and equipment which are unique to the program. The Commission was given the responsibility for controlling the use of atomic power, the exploration of its nature, its implications and potential applications, and the protection of us all against its dangers.

The Commission also was charged with the paramount responsibility of "assuring common defense and security" as defined in the Atomic Energy Act, which involves extensive operations in the fields of military applications of atomic energy, and in establishment of controls over scientific and technical information.

Development and production of weapons and fissionable materials continues to be the central concern of the national atomic energy program and of the Commission, but there are industrial and scientific plans and operations large in scope and almost without precedent in their entire content. The probable program developments in basic research are almost without limit. Emphasis is being placed on medical and biological research, with considerable attention directed toward the study of cancer.

Atomic energy is in reality a huge new inaustry. Some billions of dollars have been spent since 1943. Hundreds of millions more are now being expended, or contracted to be expended. It would seem only reasonable to assume that sizeable amounts will be expended for many years to come.

As you can readily see, the Commission in 1947 had on its hands not only military and scientific problems, but it also had taken over a colossal management problem involving the simultaneous development of past financial history and its integration with proper accounting methods and controls. Reliable accounting data had to be made available which would tell the Commission where it had been financially, where it is financially, and where it may reasonably expect to be in periods yet to come.

The Organization of the AEC

Basically, the AEC is quite similar in its structure to a holding company. The parent is the Washington Office. Five Commissioners may be said to constitute the board of directors. A general manager together with his deputy discharge such executive and administrative functions as the Commission may direct. There is a Division of Research, a Division of Production, a Division of Reactor Development, a Division of Biology and Medicine and a Division of Military Application—with administrative divisions as are necessary for successful

As an opponent for an accountant, the atom becomes formidable. In the first place, he can't see one. If he could, he probably wouldn't know what he was looking at. That is just part of it. Only a scientist can tame an atom, and almost no one can tame a scientist, except perhaps his wife. Trying to reduce such a situation to generally accepted accounting principles consistently applied is both elusive and illusory

operation such as those of the Controller, General Counsel, Organization and Personnel, Public and Technical Information Service, Security and Intelligence, *etc.*

The operations in the field are under the direction of five decentralized Offices of Operations—Chicago, Hanford, New York, Oak Ridge and Santa Fe (Los Alamos). These five offices, except in the field of raw materials, have responsibility for operations under their individual direction.

How AEC Operations Are Carried Out

The operations of the Commission are carried on by private and governmental research, construction, and production contractors under the direction of the five decentralized offices. Thousands of contractors, subcontractors, and suppliers have taken part in the atomic energy program since its inception. Many of the contractors have been universities and colleges. Many have been industrial organizations. There are personal service contractors, such as Architects-Engineers, Certified Public Accountants, Management and Industrial Engineering firms, *etc.* Other government agencies and outside organizations have been assisting in the program.

In Washington, financial accounting (including fiscal), cost accounting, auditing, budgeting and financing are under the direction of the Controller. He also has charge of the over-all insurance program of the Commission, which is a sizeable operation in itself. In each of the five field offices, many of the same activities have been placed under a Director of Finance, who is functionally responsible to the Controller, for purposes of integrated control and policy implementation, but administratively independent of the Washington Office.

The accounting inheritance from the Manhattan Engineer District was a product of the emergency. War Department accounting methods were used. The emphasis was almost entirely on fund accounting. Such cost accounting as was done was done Army style, which had little, if any, resemblance to industrial cost accounting. The Manhattan Engineer District had as its principal, and in reality its only, objective, the development of the A-bomb. There wasn't time to develop and install (even if there had been indications of a future need) accounting systems and procedures adequate for a peacetime agency with a continuing program. It had a job to do and did it, largely without the benefit, or handicap, of accounting.

Our Peacetime Approach

As might be expected, the Commission first had to review the existing methods of accounting when it took over. This required many months of time, considerable use of manpower, and the task could not be satisfactorily completed because of lack of basic records. Operations had to be observed to determine both current and future accounting needs. Industrial accounting techniques had to be developed and utilized for all of the industrial and construction activities of the Commission. Cost accounting for both programmatic and pure research was found feasible and was instituted rapidly wherever possible. Agreement had to be reached for the installation of departmental cost accounting procedures in the research laboratories largely managed by scientists who looked upon accounting systems as an infringement on freedom of both thought and actions. Public accounting methods had to be extended rapidly to the fields of financial accounting and auditing. Use was made of independent Certified Public Accountants' services wherever necessary in the accounting program. Services of management and industrial engineering firms were utilized in many instances.

It was, and is, the desire and intention of the Commission that financial records shall be kept in conformance with generally accepted accounting methods consistently applied, and that public accounting standard audit procedures shall be used to the limit of their applicability.

Every phase of the atomic energy program brings up the problem of security. Accounting is no exception. Dollar figures in accounting reports conceivably could reveal information of vital importance. For that reason, all accounting records and data are treated as if they were restricted, so far as the public is concerned. No one is permitted access to such information who does not possess security clearance. This presents special problems. All Commission personnel are investigated by the Federal Bureau of Investigation and by the Commission before they are employed and brought on duty. In many cases, this means that months have elapsed between the first contact with the employee and his reporting for duty. In a rapidly developing accounting program, this is a major handicap but it is a necessity. Full clearance is also required in the case of General Accounting Office personnel, who are to have access to financial documents. Independent public accountants undergo the same restrictions. When an accountant has been investigated, much more is known about him as a rule than any civilian employer would ever know. There is no question whatever as to his loyalty to our Country. It has to be that way, because he may have to have access to places and to information connected with all phases of the atomic energy program.

Under the Manhattan Engineer District, contractors generally were reimbursed for actual direct costs readily determinable by audit. Overhead usually was allowed on a negotiated basis with little emphasis on accounting determination. Fees were also a matter of negotiation. With the transition to a peacetime basis, it became obvious that overhead rates had to be based on "actual" costs if sound accounting rules were to be applied. The incorporation of this principle in contracts with educational institutions particularly has presented a real accounting problem. The determination of that portion of an educational institution's overhead properly attributable to the operations under one of our contracts is a difficult matter. Overhead never has been a matter of real operating concern to educators. Besides, most educational institutions use some variety of fund accounting system which can be more concealing than revealing, and which does not lend itself to ready overhead determination. Educational institutions learned during the war also that overhead allowances on government contracts are a fine source of revenue. Through their associations, they developed a formula for overhead determination which is not acceptable to the Commission for various reasons. We are now in the process of trying to reach agreement with representatives of the associations on a formula which will be based on sound accounting principles as we see them.

New Financing—Accounting Plan

It is the procedure under most government contracts that the contractor be reimbursed through the submission of public vouchers supported in great detail by sub-vouchers and documents covering all phases of procurement and payment. The Commission, until July 1, 1948, followed this plan generally. In early 1948 the Comptroller General of the United States gave the Commission permission to institute a new method of finance. Under this plan, operating funds are advanced to the contractor. At the end of each month, the contractor sub-

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mits detailed Statements of Operations, of Expenditures, and a Balance Sheet, accounting for his operations and for funds expended. Reimbursement is based upon a single monthly voucher tied into these accounting statements and to the accounting records from which they were taken. Field audits of a public accounting type are made not less than quarterly of the contractors' records for purposes of verifying the accuracy of the submitted reports. Financial reports from these integrated contractors are consolidated with Commission reports, just as if the contractors were subsidiary corporations under a parent company. We believe that this plan is superior in that: (*1*) it places full responsibility on the contractor for financial management; (*2*) it institutes audit methods which really go behind the documentary evidence to the underlying facts; (*3*) it eliminates a tremendous amount of paper and clerical work; and (*4*) it provides useful accounting information for control purposes currently. From the standpoint of sound accounting and auditing it has been a great forward step in government accounting. I should add that the Commission independently developed and put in operation many of the reforms which were subsequently recommended for the government in general by former President Hoover's group.

The Commission was faced with an enormous task in accounting for fixed assets. Prior to July 1, 1948 almost all property records had been established under Army methods and in accordance with TM 14-910. This means that generally records had been maintained for property by description, not on a dollar basis. There were no subsidiary property ledgers and no control accounts generally speaking. Actual responsibility for property had been placed on a "property accountability" officer, who was considered personally responsible for property assigned to his control. Property accounting, therefore, was a highly detailed concept which was not feasible on a large scale. There weren't enough employees to carry out the details.

The Commission has adopted methods of accounting for property which are comparable to those used in industry. IBM equipment has been utilized wherever possible. Property is valued on a dollar basis and controlled through general ledger accounts. Full consideration is being given to valuation, depreciation, and obsolescence factors. Capital assets acquired prior to July 1, 1948, have had to be valued by independent appraisal before being brought into the books.

The Commission has some extraordinary considerations in accounting for its fixed assets. In a program which is so new and so experimental, the determination as to whether an item should be capitalized or charged off to expense often cannot be made readily. As was discovered at Oak Ridge during the war, a new development may render obsolete plant or equipment which normally would appear to have an extensive life, and which may have cost hundreds of millions of dollars.

There is the problem of depreciation for cost accounting purposes. For example, what is the probable useful life of a cyclotron, of a reactor (atomic pile), or of any structure or instrument used for research? Questions of this type are myriad.

Unprecedented safety measures developed to meet the equally unprecedented hazards to health involved in the atomic energy production process also affect fixed asset accounting considerations. In the application of health physics, the policy has been to take no chances. Shielding of reactors, particle accelerators and radioactive materials to minimize the chances of radiation injury has been designed with extraordi-

narily ample safety factors of materials currently available. Research may indicate that other materials will be better. Should full costs for such items be capitalized, or should part or all of them be written off at the time of construction and installation? Answers to this and to similar questions are not to be found in any book. It is purely a matter of judgement based on the best information available at the time the decision has to be made.

Fiscal Accounting Complications

The Commission has had many unique problems in connection with its accounting for allotments, obligations, and expenditures. When financial operations were taken over from the Manhattan Engineer District, there was a lack of analysis of any kind of obligations and expenditures. Using July 1, 1946 as a starting point, Commission accountants set out to make an analysis of these items by functions and by areas. This turned out to be an extremely difficult task, but it was done after a fashion. There have been a multiplicity of fund appropriations. In some cases, it has been impossible to identify the funds which were obligated against a given contract in order to identify payments being made under that contract. Last year, the Commission had at its disposal appropriations for the years 1942–1947, 1947–1948, 1948 and 1949, out of which payments had to be made, and in addition had contract authority. In many instances it was necessary to adopt the "first-in-first-out" approach in disbursing them because of the lack of adequate identification of obligations. Beginning July 1, 1949, we went on a "cost type budget" and greatly simplified our fund picture, but it still is extremely complex.

Funds of most governmental bodies are appropriated by Congress to cover one fiscal year only. Under the Atomic Energy Commission Act, "Funds appropriated to the Commission shall, if obligated by contract during the fiscal year for which appropriated, remain available for four years following the expiration of the fiscal year for which appropriated." The accounting problem would be much simpler if appropriations were made on a continuing basis, and if accounting reports were prepared on a going concern basis as in industry. We are headed in that direction, but we are obliged to conform to many existing laws and procedures. As it is now, we have two complete accounting systems—one to meet government fiscal requirements and another on an industrial basis.

Costing of industrial operations under the Commission is feasible and can be carried out in a great many cases to satisfactory unit costs. Costing of research activities on a rational basis presents all kinds of problems. There is the distinction to be made between pure and applied research and the determination of cost categories under each class. The determination of expendable items as opposed to capital items has to be made, even though at times the accountant may not know what the items are after he has been told. Some instruments and devices used in atomic science are like nothing else in this world. There will always be the problem of trying to get a distinguished scientist to even consider keeping records on the time he has spent. Yet, cost accounting cannot be ignored in such fields.

It is one thing to arrive at a cost-per-egg-per-hen-hour on a chicken farm, but it is something else again, for example, to get the cost of production of isotopes "per millicurie." A "millicurie" is a measure of atomic disintegrations. One millicurie is 37,500,000 disintegrations per second. Determining the cost of many developed instruments can be only a "reasoned guess" at best. END

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Engineering Aspects of Nuclear Reactors—I

In this first of four articles, some of the basic components of the pile are described. The factors influencing the size and shape of the different types of piles—fast, intermediate and thermal—are described along with the nature of the nuclear fuels used

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FUNDAMENTAL to the operation of nuclear chain reactors (or piles) are the fission process and the chain reaction. Since these processes have been adequately described elsewhere,* no explanation of them will be given in these articles. However, the following significant facts are important as background for this discussion.

First, let us define a nuclear fuel as a fissionable material that will support and propagate a nuclear chain reaction under the proper conditions. This is a necessary limitation because there are many materials that can be fissioned under the proper impetus, but not all of these will support a nuclear chain reaction.

Next, every time a nucleus of a fissionable material such as U^{235} is fissioned, nuclei of two new chemical elements (the fission fragments) are formed. Therefore, in a chain reaction in a nuclear reactor, the nuclear fuel is constantly depleted and is replaced by waste products, many of which are neutron absorbers or literally "poisons" because they steal neutrons from the chain reaction.

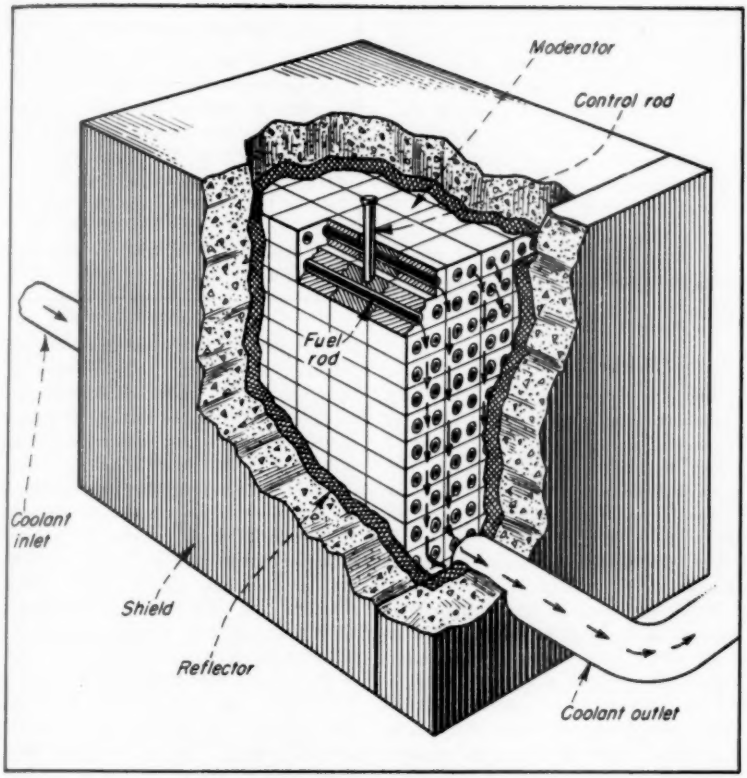
The fission fragments are intensely radioactive and decay by a succession of particle emissions and conversions, accompanied by gamma radiation. Since the fission fragments formed may vary over a large portion of the Periodic Table, their mode of decay may also vary, and their half-lives may be anything from a small fraction of a second to many years. Therefore, these fission fragments not only poison the nuclear fuel but usually contaminate it with long-lived radioactivity that makes it impossible to handle the fuel in any way except by remote control.

In addition to the various forms of radioactivity released by the fission fragments, the act of fission itself also releases gamma radiation, usually with energies in the range of 1 to 5 Mev. Therefore, once a reactor is, or has been, in operation, it becomes an intense source of radioactivity that can be quite hazardous.

Another significant fact is that the fission process also releases from one to three neutrons for each neutron absorbed in fission. These neutrons, which are released at energies of about 1 to 2 Mev, are used to propagate the chain reaction.

Lastly, the fission process releases about 200 Mev of energy per fission. Of this, about 80% is manifested as kinetic energy of the fission fragments. This kinetic energy, in turn, is converted to heat as these recoiling fission fragments are stopped by other fission

* For example, "The Science and Engineering of Nuclear Power," edited by Clark Goodman (Addison-Wesley Press, Inc., Cambridge, 1947).



Artist's conception of a basic nuclear reactor

fragments or by nuclei of the original fissionable material. As for the remaining 20% of the energy released, about 2½% is carried away by the neutrons released at fission, and is usually absorbed in the moderator of the reactor. About 12% of the original 200 Mev is carried away by the radioactivity produced at fission and during the decay of the fission fragments. Some of this will be absorbed in the reactor proper, some in the shielding, and the balance will escape. Of this 12%, about 2½% occurs as the energy of the prompt gammas produced by fission, while the remaining 9½% occurs as the radioactivity of the decaying fission fragments. The balance of the 200 Mev is lost and cannot be utilized.

Before we consider the actual engineering design and construction of reactors, let us first see what kinds there are and review some of the unique characteristics and idiosyncrasies that confront the designer.

A pile may be any size, shape, or configuration depending upon its purpose, the location of its use, the various materials of which it will be constructed, and the availability of these materials. In

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general, piles fall into two major classifications—those in which the energy released is to be dissipated as a waste product, and those in which this energy is to be converted into useful power. Examples of the former are piles used as pure research units or those used for the production of isotopes, in which the level of the power produced by the pile is not economically convertible to practical use. Examples of useful power piles, of course, are any reactors used as the power sources for mobile or stationary power plants.

Size and Shape of Pile

The size of the pile itself may vary anywhere from a tiny sphere about a foot in diameter up to the size of a house, depending upon its shape, the type of fissionable material or nuclear fuel employed, the energy level at which fission takes place, and a number of other factors that will be discussed in this series.

Its shape may be any simple geometrical solid, in which the three principal dimensions are approximately equal. In general, it may be either a sphere, a cube, or a right rectangular cylinder or prism. While it is desirable to maintain the three principal dimensions approximately equal, it is possible to vary the dimensions, provided the maximum dimension is made not more than about twice the least dimension.

The active section of the pile may be a homogeneous mixture of its components or these may be arranged in a heterogeneous or geometrical pattern in which the components are separated into discrete and separate masses.

Types of Piles

All piles may be subdivided into three general types, according to the energy of the neutrons that produce fission. The first of these is the "fast" pile, in which the neutrons produce fission at practically the same energy at which they themselves are released by fission. In this type of reactor, it is desirable to have the fission-produced neutrons remain in or reenter the fissionable material to produce further fission as soon as possible and with as little energy loss as possible. Therefore, this type of reactor must be made of almost pure fissionable material, with as little extraneous material in it as possible. Fast reactors are, in general, the smallest type reactors that can be made, although they may actually require more fuel than larger reactors.

The second type of pile is the slow or "thermal" pile, in which the neutrons that produce fission are all at about thermal energy. Since these neutrons have been produced in fission as fast neutrons with energies around 1 Mev and must have energies of only about $\frac{1}{40}$ ev when entering the fissionable material to produce further fission, it is obvious that some foreign material must be introduced into the reactor to degrade the energy level or slow down these neutrons to thermal energy. Such a material is called a "moderator," which may be either a very light material, a heavy material, or both. The amount of moderator needed is very large compared to the amount of the fissionable material in the pile. Accordingly, thermal piles, in general, are the largest of the three types (although there is some overlapping in size ranges).

FUTURE ARTICLES

In the second article in this series, Mr. Ohlinger will continue his discussion of the components of the pile. The third article will contain a description of the construction, assembly and operation of the pile. In the last article, nuclear power plant systems and the limitations and applications of nuclear energy will be described.

The third type of pile is the "intermediate" pile, in which the neutrons that produce fission are at some energy level intermediate between thermal energy and the energy at which they are produced by fission. Intermediate piles may operate with neutrons at any energy level between thermal and fission or even at several different energy levels, depending upon their construction and composition. Therefore, intermediate piles, in general, are intermediate in size between thermal and fast piles, although there is no sharp line of demarcation. Some intermediate piles may be larger than some thermal piles, and, in some rare cases, a fast pile might actually be larger than an intermediate pile. However, the above statements about the sizes of the three types of pile are good rule-of-thumb criteria.

It is even possible in some cases to expand the range of energies at which fission takes place to extend from fission energy part way down through the intermediate region, or from some intervening level all the way to thermal energy. Such piles would be combination fast and intermediate reactors or intermediate and thermal reactors with some of the characteristics of each.

Nuclear Fuels

Other factors affecting the size of the pile, irrespective of the neutron energy levels, are the kind of fissionable material or nuclear fuel, the availability of the fuel, and the form in which it is available. While many different materials can be fissioned under the proper conditions, there are at present only three practical nuclear fuels, of which only one occurs in nature.

The first of these, U^{235}, is an isotope that occurs in natural uranium in the proportion of one part in 140. Since it is chemically inseparable from the natural uranium; the U^{235} must be separated by mechanical or physical processes that are both expensive and extensive when any sizeable quantity of U^{235} is to be produced. Such processes are gaseous diffusion through porous barriers, liquid thermal diffusion, centrifuging, and electromagnetic separation. These processes either give almost complete separation in one stage with a very poor yield, or else a very good yield but a very poor separation. Good separation and good yield are never both obtained. Hundreds and even thousands of stages are required to achieve complete separation of the pure U^{235}.

The other two nuclear fuels, plutonium (Pu) and U^{233}, are produced by neutron bombardment of U^{238} and thorium (Th), respectively. When these "fertile" materials, U^{238} and Th, are bombarded by pile neutrons, they absorb some of these neutrons and undergo the following reactions and radioactive decay:

$$_{92}U^{238} + {}_{0}n^{1} \rightarrow {}_{92}U^{239} \xrightarrow[23\ m]{\beta^-}$$

$$_{93}Np^{239} \xrightarrow[2.3\ d]{\beta^-} {}_{94}Pu^{239}$$

$$_{90}Th^{232} + {}_{0}n^{1} \rightarrow {}_{90}Th^{233} \xrightarrow[23\ m]{\beta^-}$$

$$_{91}Pa^{233} \xrightarrow[27\ d]{\beta^-} {}_{92}U^{233}$$

Once formed, these new nuclear fuels in turn can fission with neutrons of any energy, just like U^{235}. Therefore, as the concentration of the new fissionable material builds up within the fertile material, a point will be reached at which the rate of production of the fissionable material will just equal its rate of disappearance by fission. Beyond this point, it will be impossible to build up any higher concentration of fissionable material, regardless of the length of time of exposure.

Before this saturation occurs, it is desirable to remove the fertile material from the pile and separate the new fissionable material from it. Since the

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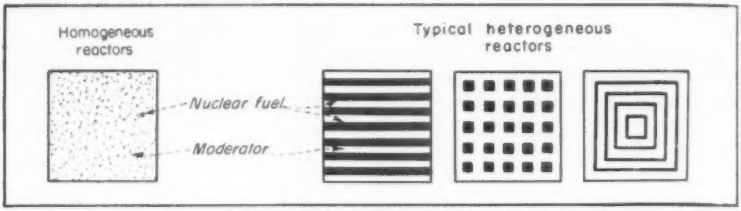

FIG. 1. Active core—contains a nuclear fuel, possibly a diluent, and, in some cases, a moderator

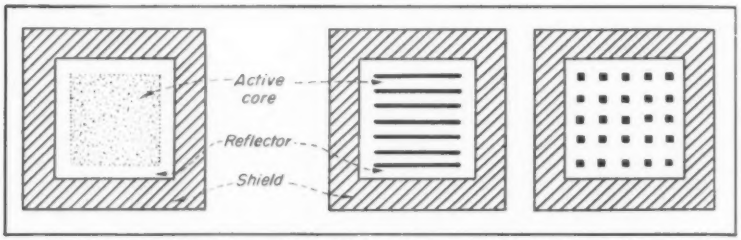

FIG. 2. The pile proper, with the reflector and radiation shield

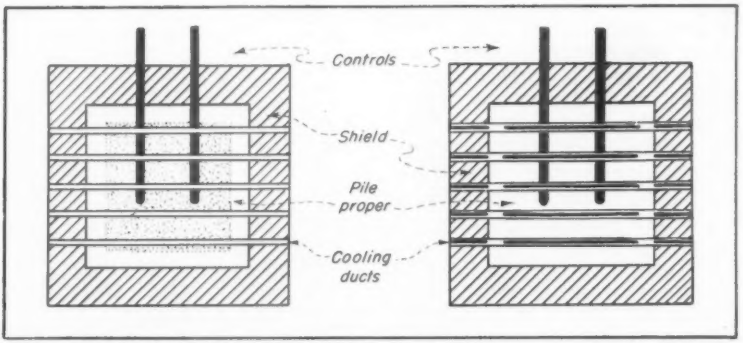

FIG. 3. Sketch of pile showing control rods and means of energy removal. The ends of the cooling ducts must be plugged, baffled or shielded to prevent the escape of radiation through these holes in the shield

fissionable material is a different chemical element from the original fertile material in the two cases, it is apparent that it can be removed by chemical processes. These may be the coprecipitation techniques employed in tracer chemistry, solvent extraction, ion exchange, or even volatilization in some cases. Distillation is not practical for this particular separation. One thing that should be noted is that these processes are almost as difficult in their way as the mechanical processes are in theirs because the concentration of fissionable material within the fertile material will be extremely small. Even a small contamination, such as the natural uranium that usually is found asso-

ciated with thorium, can completely blanket the results of the chemical separation.

In some cases, for reasons of economy or mechanical simplicity, it may be desirable to stop the mechanical separation processes at some intermediate stage at which the concentration of U^{235} in the uranium is greater than in natural uranium, but is at less than complete purity. Such a uranium is called an enriched uranium and may contain anything from a few percent up to 90% or more of U^{235}, depending upon the designer's choice.

With the artificial nuclear fuels, it is generally impractical to utilize them in their unseparated state in the original fertile material. However, there may be occasions in which one of these artificial nuclear fuels would be alloyed with some other material, such as the separated U^{238} or Th, for reasons of mechanical simplicity or stability. When a natural or artificial nuclear fuel is mixed mechanically or chemically with another material as a carrier, the diluting material is called a "diluent."

Thus, it can be said that, in general, other factors being equal, the purer the nuclear fuel, the smaller the reactor, whereas the greater the dilution by the U^{238} or Th carrier or diluent, the larger the pile.

The effect of the arrangement of the nuclear fuel within the reactor is, briefly, this: Other factors being equal, a homogeneous mixture of the nuclear fuel (and its diluent, if any) with the other pile components will usually result in a larger pile than that occurring with a properly designed heterogeneous arrangement of the fuel and diluent with the other pile components.

Components of Basic Pile

Basically, a nuclear reactor is a relatively simple piece of power-producing equipment. The core or active section of the pile (see Fig. 1), in its simplest form, may consist merely of a mass of fissionable material or nuclear fuel. In other cases, this fissionable material may be mixed with some non-fissionable material as a diluent for reasons of economy, mechanical desirability, or the production of new nuclear fuels. In still other cases, the fissionable material and its diluent, if any, may be mixed either homogeneously or heterogeneously with the moderator.

It is in this simply constituted core that the nuclear chain reaction takes place, and it is here that all of the power produced by this reaction is released.

A relatively thin blanket of material called a reflector (see Fig. 2) usually surrounds the active section of the pile. This material has a function similar to that of the moderator and may frequently be simply an extension of the moderator beyond the active section of the pile. However, this reflector does not contain any fissionable material. Not all piles use reflectors because the reflector increases the over-all size and weight of the reactor. However, the use of a reflector usually brings about a saving in nuclear fuel.

The next component we find in a practical pile is a radiation shield (Fig. 2) that usually encloses the entire reactor and reflector (if any). This shield generally consists of a homogeneous or heterogeneous mixture of several different materials of different characteristics. It must almost always be heavy and massive because it must protect personnel and equipment from hazardous radiation.

These components define the physical extent of the pile, but there remain two other components to complete the basic picture.

One of these is a control system (Fig. 3) for setting and controlling the energy released by the pile and insuring its safe operation at all times. A practical pile actually requires three different functional controls. These may

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exist as three independent control systems or may be combined into one or two control systems, each capable of performing one or more functions.

The other is the means which must be provided for removing the energy released in a pile (Fig. 3), regardless of whether this energy is to be utilized as useful power or is to be dissipated as a waste product. Piles that are designed purely for research or for isotope production may often release their energy at a level that is totally impractical for conversion to useful power, but, even in piles designed primarily for the production of power, the energy released within the pile must be brought out of the reactor before it can be converted to useful power. Once the energy released in a pile has been brought outside the reactor, its dissipation or utilization as useful power becomes the problem of conventional equipment.

To understand better the engineering and construction of nuclear reactors, let us consider the functions and characteristics of the pile as a whole and of each of the above pile components, individually and in their relation to each other and to the reactor as a unit.

Pile as a Whole

A nuclear reactor is any unit in which a nuclear chain reaction can be started and carried on at any desired rate. This inference of controllability does not exclude the atomic bomb under this definition because it actually is a nuclear chain reactor in which the desired rate of expanding the chain reaction is the maximum attainable. However, all reactors except the bomb should be controllable at the discretion of an operator.

The first thing to recognize is that the pile is not a power plant in itself but is simply a new and unusual source of energy in the form of heat. In a power plant, the pile merely replaces the furnace, firebox, or combustion chamber of the conventional power plant, while the equipment that utilizes this heat or converts it into other forms of useful energy is the same conventional equipment with which engineers are now familiar. The pile is simply a box in which any amount of heat can be produced, and it is the problem of the engineer to remove as much of this heat as is required.

It is not meant to imply that there is no other way of realizing power from nuclear energy except by heat. Studies have been and will continue to be made on removing the energy of a pile directly as electrical energy or by chemical means but, in the present state of the art, its removal as heat is the only practical solution that has been developed.

Homogeneous vs Heterogeneous Piles

A heterogeneous arrangement of the components of the pile core generally requires less nuclear fuel for the same size of pile than a homogeneous arrangement of these same materials. In addition, it may not always be possible to make a homogeneous pile work, even though a heterogeneous arrangement of these same materials can be built that will function as a nuclear reactor. The use of natural uranium is the outstanding example of this peculiarity. Calculations indicate that it cannot be made to sustain a chain reaction by itself or mixed homogeneously with any other material (except possibly heavy water). Nevertheless, this same natural uranium can be made to propagate a chain reaction with at least one or more potential moderators if the uranium is properly arranged in a heterogeneous pattern.

Homogeneous reactors are often easier to construct and their components often easier to replace. However, replacing the active core of a homogeneous type of pile means the replacement of the entire homogeneous mixture of fuel, diluent, and moderator, while a

PILE ENERGY RELEASE PARADOX

THERE is one idiosyncrasy about nuclear chain reactors as power producers that may seem paradoxical to engineers. To a first approximation, the amount of energy that may be released within a reactor and, hence, the amount of power that may be produced thereby, does not depend upon the size of the reactor as determined by nuclear considerations. Any amount of power from a few watts up to hundreds of thousands of kilowatts may be produced from any size pile provided this energy can be removed from it. In the smaller piles, it is interestint to note that the limitation on the power production is not a nuclear one, but one that is dictated by the mechanical and thermodynamic ability of the engineers to remove the desired amount of power from the small volume of reactor required by the nuclear physical considerations.

corresponding heterogeneous pile can be designed so that only the fuel and diluent need be replaced at any particular time. Not only is the replacement simplified in this manner, but the subsequent reprocessing of the materials from the pile core is also simplified, since the moderator material constitutes a mass many times that of the nuclear fuel and its diluent, and any fuel processing system would have to handle all this extraneous material.

All piles, no matter how carefully designed, have some lack of uniformity in the release of energy throughout the core. Therefore, it is inevitable that there will be thermal gradients and nonuniform linear expansion of the reactor components. Since most of the heat produced in a pile is produced right in the nuclear fuel itself, it is usually easier to remove this heat and prevent excessive thermal gradients and unequal expansion in a heterogeneous than in a homogeneous pile.

The Nuclear Fuel

Previously, we discussed the nature of nuclear fuels and what the most practical nuclear fuels are. One significant fact is that all three fuels mentioned are materials that will fission not just with neutrons at thermal energy, but with neutrons of any energy. The only difference is that the probability of fission at lower energies is so much greater, this probability decreasing as the energy of the neutrons causing fission increases.

In the following discussion of the forms in which the nuclear fuel can be used, any reference to the form of the nuclear fuel includes both the nuclear fuel and its diluent, where such a diluent is used.

All of the nuclear fuels are metallic by nature and workable accordingly. They can be prepared in many shapes, such as tubes, balls, sheets, long rods, or short slugs. These metals can be comminuted into a powdered form or alloyed with other compatible metals.

Since these metallic fuels are very active in the presence of oxygen, the fuel can be used in the form of the metallic oxides to prevent subsequent oxidation. Carburization in the presence of carbon at elevated temperatures can be prevented by the use of a metallic carbide. Both the oxides and the carbides have the added advantage that they are refractory materials and withstand pile operation at elevated temperatures. Other chemical compounds such as the hydrides or sulfides of these metals might be desirable forms for specific applications.

For piles in which the nuclear fuel is in a powdered form, a powdered oxide is probably the best form of the fuel, although the carbide or the sulfide

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might be used. For piles in which the fuel is dissolved in a carrier, uranyl nitrate and uranyl sulfate are probably the most soluble compounds of uranium as a fuel. When the fuel is to be inserted into the pile in a liquid state at normal temperatures, uranium hexafluoride, UF_6, is the only known liquid compound of uranium as a fuel. Although fluorine is also a possible moderating material and as a compound might constitute a suitable mixture for a homogeneous reactor, the fission in any nucleus of uranium will break up the molecule and liberate free fluorine ions in the fluid. From an engineering standpoint, this is highly undesirable because of the extremely corrosive effect of free fluorine, especially if any water is present.

Coating the Fuel

When fission occurs near the surface of any of the individual units of fuel, it is possible for one of the recoiling fission fragments to recoil out of the fuel into the adjoining media. Since fission fragments are radioactive, this contaminates the adjacent media with radioactivity that may have no significance in some cases, but may be very serious in others where the immediately adjacent medium is a circulating fluid for carrying the heat out of the pile. The fluid will carry the radioactive fission fragments out of the pile with it and contaminate all the external equipment downstream of the pile with undesirable radioactivity. Therefore, it is preferable in many piles to provide a protective coating around the nuclear fuel in order to stop these recoiling fission fragments and prevent their contaminating the adjacent materials.

In addition, there have been and will be many piles in which the nuclear fuel must be protected against corrosion, erosion, or oxidation. These, too, will require protective coatings around the nuclear fuel units. Fortunately, it is possible for the same coating to serve both purposes.

The coating of very tiny fuel units, such as powdered material, is not practical without the introduction of prohibitive quantities of the coating materials. Therefore, the fuel in homogeneous reactors will rarely have a protective coating. This introduces the objection that much of the auxiliary pile equipment external to the pile will also have to be encased in radiation shielding. In some cases, however, the contamination of external equipment can be avoided by flowing the coolant for the pile through special channels defined by tubes or sheaths that meet the specifications for the protective coating.

The coating must be resistant to corrosion by the surrounding media, completely inert to the nuclear fuel and its diluent, and must be impervious to the fuel, diluent, and the surrounding media. It must have a high thermal conductivity, a relatively low probability of neutron capture, and must be comparatively easy to form so that it can be shaped to the fuel and properly bonded to it in order to obtain good heat transfer from the fuel to the coating. For high temperature piles, the coating must also be one that is refractory and will retain all of the desirable properties at elevated temperatures. The most generally used coating is aluminum.

While a protective coating is important in most nuclear reactors, it is a nuisance in the subsequent processing because it must be removed before the fuel unit can be purified or reprocessed in any way.

The Moderator

The moderator is a material that slows down or moderates the neutrons from the energy at which they are produced by fission to the energy at which they are to reenter the nuclear fuel and create further fission. Since every

material, with the possible exception of helium, has a measurable probability of capturing neutrons at any energy, it follows that the use of a moderator will rob the chain reaction of some of its neutrons.

Since we are trying to slow the fission-produced neutrons down to very low energies because of the increased probability of fission at these low energies, it is obvious that any parasitic capture of these neutrons while they are being slowed down will partially defeat the purpose of the moderator. Hence, one of the first requirements of the moderator is that it should have a relatively low probability of neutron capture.

Moderators slow down neutrons by either of two scattering processes—elastic or inelastic scattering. Although it is said that the neutron actually enters the nucleus in both of these cases and a neutron (not necessarily the same one that entered) is subsequently ejected, the processes differ markedly in their effect upon the nucleus. In the first case, the nucleus is not excited by the collision and does not give off any radiant energy as gamma radiation. Instead, the two particles behave exactly as if they followed the laws of elastic collision of rigid bodies. In the second case, the nucleus is excited by some of the excess energy of the neutron and this causes emission of gamma radiation.

In elastic scattering, the light elements are the best moderators because they cause the loss of the maximum average fraction of energy at each collision. As far as energy loss per collision is concerned, the lighter the element, the better the moderator. However, the competing process of neutron capture may be so great that a light element will be useless as a moderator despite its low atomic weight.

If we consider the first twelve or fourteen elements in the Periodic Table, we can eliminate helium and neon immediately because they are gases, and therefore are too low in nuclear density to be practical moderating materials. Likewise, since they are noble gases, there are no chemical compounds of these elements that might be used. Hydrogen, nitrogen, fluorine, and oxygen are also gases so that they cannot be used in their natural state as moderators, but solid and liquid compounds of these elements might be employed. However, hydrogen and nitrogen are neutron absorbers, so that compounds of these elements can only be used at the expense of additional nuclear fuel.

Lithium has a rather high and boron a very high probability of neutron capture at lower energies, so that these solids are impractical as moderators. Magnesium, aluminum, and silicon or their compounds are possible, but not too desirable moderating materials. However, magnesium or aluminum and their oxides might be substituted for beryllium (see below) and its oxide in cases where the extra fuel required thereby is less important than the problem of obtaining the beryllium or beryllium oxide. Sodium is too active an element for ordinary use and fluorine is too corrosive an element, particularly in the presence of water.

This leaves only beryllium and carbon or their compounds as the good, solid moderators among the light elements. Beryllium is one of the very good moderating materials because of its low capture cross section. It has all the advantages of a metal, although it is expensive, and not very abundant in its pure metallic state. Its compounds, beryllium carbide and beryllium oxide, are refractory materials so that they make good moderators for power-producing piles that must operate at elevated temperatures. Beryllium also has the advantage that

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$(n,2n)$ and (γ,n) reactions in the beryllium under pile conditions contribute a few extra neutrons to the chain reaction.

Carbon in the form of graphite was the first moderating material ever used and is the moderator employed in many of the existing reactors because it is less expensive even in its pure state, more abundant, easy to work, and has good physical properties. Likewise, it is a refractory material and can be utilized in piles operating at elevated temperatures, in the proper atmosphere.

One other light element that does not appear in the Periodic Table, but is one of the best moderators of all because it has such a very low capture cross section, is the heavy isotope of hydrogen, deuterium. As a gas, deuterium is, of course, useless as a moderator, but in compounds like the deuterocarbons or heavy water (D_2O), this material forms an ideal moderator for piles in which the operating temperature does not prohibit the use of these compounds. Deuterium and its compounds are very expensive, but have the added nuclear advantage that, like beryllium, deuterium undergoes a (γ,n) reaction in the pile that contributes some neutrons to the chain reaction.

If there is no objection to using the extra nuclear fuel required thereby, other materials might be used as moderators that are less efficient from a moderating standpoint, but are more desirable for other reasons, such as greater structural or mechanical stability, or better thermal or chemical properties. In these cases, there are any number of elements or compounds that might be used depending upon the extra amount of nuclear fuel that can be sacrificed and the properties of the particular materials. Examples of these would be zinc, zirconium, columbium, copper, or their compounds, and the usual constituents of alloy irons and steels. Even such heavy elements as bismuth and lead or their compounds might be used as moderators in some intermediate piles. For high energy piles, there are other heavy elements that might be used that could not be used for thermal piles because of their high neutron-capture property in the intermediate region.

Moderators for Specific Purposes

The choice of materials for the moderator for any specific pile depends upon a number of factors that may be quite contradictory and require careful weighting in making a choice. The type of fuel, the type of pile and the relative amount of diluent in the fuel are all factors affecting the choice of moderator, irrespective of the purpose of the pile. To reduce the amount of nuclear fuel to a minimum, metallic beryllium or deuterium or beryllium compounds with oxygen or carbon appear to be the best moderators. When natural uranium is used as the fuel, any of these materials or graphite can be used as the moderator, depending upon the pile configuration.

For piles intended only as research units or isotope producers operating at relatively low temperature levels, almost any moderating material can be used that is compatible with the balance of the operating conditions. For piles intended for the production of useful power at elevated temperatures, it is obvious that most of the liquid moderators will be useless and that refractory elements or compounds must be used. For thermal piles, this means beryllium oxide or carbide, graphite, or possibly some of the other metallic oxides, carbides, or nitrides if the additional fuel required thereby is not objectionable. For intermediate piles, refractory elements such as tungsten, tantalum, and other high

melting metals or refractory compounds such as the oxides, carbides, and nitrides of heavier metallic elements may be added to the list of high temperature moderating materials.

Of course, all compounds are subject to decomposition under pile irradiation. Where this decomposition causes the liberated elements to undergo a change in phase from that in which they existed in the compound, the change in nuclear density occasioned by this phase change will change the reactivity of the pile and complicate the operation. Similarly, any bubble formation due to free boiling conditions must be suppressed by high superimposed pressures to avoid the same problem.

There are other factors involved in the choice of a moderator that can only be touched upon lightly in this discussion. For example, chemical compatibility with the fuel and its diluent, with the coolant, or with protective coatings where these are used, may be a significant factor. Thermal gradients introduced by the nonuniform release of energy in a pile introduce another significant problem.

Units of Radioactivity

In November, 1947, a joint committee* of the Divisions of Chemistry and Chemical Technology and of Mathematical and Physical Sciences of the National Research Council was appointed to make recommendations regarding standards and units of radioactivity. This committee has unanimously adopted the recommendations quoted below. It is stated that these recommendations effectively divorce the curie from the disintegration rate of radium by assigning to the former an arbitrary magnitude (3.7×10^{10} dis/sec) approximately equal to the disintegration rate of radium. This arbitrary figure is, therefore, not influenced by any future revisions of the generally accepted disintegration rate of radium. This recommendation has been submitted to the Joint Commission on Standards, Units, and Constants of Radioactivity of the International Unions of Chemistry and Physics for the purpose of obtaining international agreement.

This changes, slightly, the meaning of the curie when applied to radium. For example, 1 curie of radon is no longer, on the basis of these recommendations, the amount in equilibrium with 1 gram of radium, but is the amount undergoing 3.7×10^{10} disintegrations per second. Similarly, 1 mg and 1 mc of radium are no longer rigorously synonomous. This distinction has a number of precedents in physics; for example, the international ampere, now abolished, was not quite equal to the absolute ampere and the angstrom unit is nearly, but not quite, equal to 1,000 x-units.

curie—The curie should be defined as that quantity of any radioactive species (radioisotope) undergoing exactly 3.700×10^{10} disintegrations per second.

rutherford—The rutherford should be defined as that quantity of any radioactive species (radioisotope) undergoing 10^6 disintegrations per second.

rhm—For the quantitative comparison of radioactive sources emitting gamma rays, for which disintegration rates cannot be determined, the roentgen per hour at one meter (rhm) is recommended. This is not essentially a new unit since all units involved are well established, explicitly defined, and are in common usage.

* This committee consists of L. F. Curtiss, chairman, R. D. Evans, Warren Johnson, and Glenn T. Seaborg.

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Air Pollution and the Particle Size-Toxicity Problem—I

This and successive articles are presented to point up some of the dominant problems of air pollution and to cite instances where application of recently developed methods has aided the solution of current industrial hygiene problems. Chemical toxicity problems are emphasized, with special attention given to those substances involved in atomic-energy production

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Problems arising from airborne aerosols transcend sectional limitations and are literally world-wide. As evidence of the cogency of this statement, recall that the eruption of Krakatoa between August 26 and September 9, 1883, discharged particles of sizes estimated at between 3 and 20 microns in diameter 100,000 feet into the air producing an abnormal sky haze around the entire world. This dust cloud completely circled the globe 3¼ times before final dissipation, and it was 2 years before the world's sunset cleared. From wind-swept African deserts in 1903, 10 million tons of dust were said to have fallen on England with particle sizes estimated at from 1 to 10 microns. Similarly, dust storms in the United States occurring over a 2-day period in November, 1933, raised a dust cloud 5,000 feet high which carried 1,200 to 1,500 miles deposits of particles estimated at from 5 to 50 microns.

Industrial Air Pollution

Statement of the problems. The difficulties arising from industrial airborne pollution are of more serious character than those of natural phenomena because they are more prevalent and physically and chemically more diversified. Physically, industrial waste products comprise all types of aerosols including the particulates, smokes, dusts, fumes, and mists, as well as nonparticulate vapors; chemically, they vary from elemental substances like fluorine to complex organic molecules. Effects of this material diversification range from the nuisances of low visibility and irritation of eyes and respiratory passages to differing degrees of human disability and even to death.

Industrial air pollution problems may be classed into two types: (1) those affecting the atmosphere of industrial environments, "neighborhood" contamination; and (2) those occurring within the plant itself. Examples of the first type are the Donora and the Los Angeles valley smogs and neighborhood air pollution by beryllium in Ohio; examples of the second type are beryllium oxide and sulfate plant exposures and those in the uranium industry.

Donora Smog Disaster

In Donora, Pennsylvania (population 14,000) in 1948 (*1*), a score of fatalities occurred and upwards of 5,000 individuals were made ill. Donora is one of several industrial towns nestled in the Monongahela Valley between hills rising abruptly to 400 feet on either side. Zinc smelting, steel and wire

manufacture, and slag crushing comprise its chief industries. Much shipping and rail activity further contribute to the air pollution.

Heavy smog lay in Donora for a period of 4 days. Visibility was limited to 25 feet, traffic, to 2 miles per hour. No air moved. On Saturday, October 30, illness and fatalities began to occur. In the zinc plant, 9 cases of illness were reported but no deaths. Deaths occurred only in individuals between the ages of 52 and 85 years and only in those with either active pulmonary tuberculosis, respiratory difficulties (asthma), or chronic cardiac involvement. On autopsy of 3 victims, no cause for death attributable to smog inhalation could be found. The mortality rate for respiratory ailments (0.43) and heart disease (2.7 per thousand per annum) has been shown statistically to be no higher at Donora than at other nearby towns.

Directly following the first few deaths when the unusual character of the smog condition became realized, the local authorities notified the Industrial Hygiene Bureau of Pennsylvania which, with the cooperation of the Industrial Hygiene Foundation at Mellon Institute, began an investigation into the causes of the incident. Later when time permitted a more planned and thorough investigation, the United States Public Health Service, aided by meteorologists, analysts, dentists, nurses and statisticians, surveyed the area in cooperation with local and state authorities and consultants of the industrial companies.

The chief findings were the following: (1) the indicated source of trouble was the zinc smelting plant; (2) sulfur dioxide gas was considered to be the main offending substance. SO_2 was implicated on the following grounds: First, an area of 5 miles of tree-devastated land contiguous to the zinc plant was indicative of excess atmospheric sulfur-dioxide concentration. Second, zinc-smelting plants are known to discharge large quantities of sulfur dioxide. Third, air samples for sulfur dioxide taken when the smog still prevailed showed 1.4 mg/m³; 5 hours later, when the fog had cleared, samples showed 0.2 mg/m³. Periodic analyses taken later and during the time when the zinc plant was running at half capacity showed values of from 0 to 2 mg/m³. The samples for sulfate during smog conditions showed 0.2 mg/m³, but later 0 to 0.17 mg/m³.

It seems that although concentrations of SO_2 never approached lethal values, the cause of death is best explained by the fact that overtaxed, chronically weakened respiratory and cardiovascular systems could no longer function under the contractual spasms caused by prolonged exposure to the irritant sulfur dioxide.

Fluorine was given a clean bill of health; concentrations less than 1 ppm were found and no evidence of fluorosis was observed in the teeth of children of school age in the area. More recent investigations (*2*) have inclined to attribute a toxic role to finely divided sulfur.

Los Angeles Smog Problem

Smog in the Los Angeles area (*3*) had increased by 1947 through accumulation of atmospheric wastes to such an extent that public demand for relief resulted in the establishment of the Los Angeles County Air Pollution Control District.

Certain unusual topographic features and meteorologic conditions are responsible for bringing about the high atmospheric concentrations of industrial wastes in and about the Los Angeles basin. During the day, westerly winds carry the pollutants from the industrial district into residential areas; during the night a reverse wind returns the pollutants to the industrial district.

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Dissipation aloft is prevented by an inversion layer that reduces atmospheric turbulence and normal attenuation. Moreover, the air basin is bounded by high mountain ranges that also restrict dissipation of the cloud (*4*).

Again, as in Donora, sulfur dioxide and acidic sulfates were sought as the most probable offending agents. Other less common substances are being investigated as possibly being involved, *e.g.*, hydrogen persulfides, the strong lachrymatory effects of which, at extremely small concentrations, are known. These substances coexist with hydrogen sulfide following its action on hydrocarbons. Likewise given consideration have been ammonium sulfite resulting from the combination of SO_2 and ammonia, sulfur compounds formed by partial oxidation of mercaptans to paraffinic and aromatic sulfonates, and sulfur itself.

Contrasting the contribution to air pollution by particulates with nonparticulates (SO_2), it is important to note that the dust-fall record of the Los Angeles area is actually less than that of many other industrial cities. This indicates either that the particulates are below 5 μ and are, therefore, airborne longer or that they are relatively so few in number as to contribute only in a minor way to the over-all air pollution. The blue-colored haze prevalent in the Los Angeles basin favors the interpretation of small-particle size (0.3 to 0.5 μ), but whether this is due to solid particulates has not been ascertained.

Lessons Gained from Smog Problems

The common denominators giving rise to community smogs are thus patent—the environmental topography and meteorologic conditions. Less obvious, and as yet mostly unappreciated, is the factor of condensation nuclei such as represented by sulfur dioxide vapor. These nuclei, so-called because of their hygroscopicity, causing the transformation of water vapor to particulate water droplets, play a determinant role in smog production, as shown in Table 1.

TABLE 1

Mean Number of Condensation Nuclei for Various Ranges of Dust Concentration in City Air

Dust/cm³	*Nuclei/cm³*
500	189,000
500–999	211,000
>999	223,000

It is seen that neutral dust comprises less than 1% of the number of condensation nuclei. Some evidence is now at hand in proof of this (*5*): (1) The number of condensation nuclei parallels the sulfur content of the air as shown in Table 2. (2) Sulfur dioxide is more nucleogenic* in sunlight, due to slow oxidation to sulfuric acid by ultraviolet light which in turn is highly nucleogenic. This accounts in part for the often observed phenomenon of increase in fog in early morning sunlight. Size of condensation nuclei depends upon moisture conditions. If the relative humidity is under 70%, no change in size occurs, but growth becomes rapid if humidity is greater than 70%. For dense cloud formation, only 300 to 500 condensation nuclei/cm³ are required. Accordingly, in industrial regions there is an overabundance of these nuclei.

Figure 1 shows the relation between the size of condensation nuclei and the visual range as a function of relative humidity. It is seen that the visual range decreases markedly as the size of nuclei increases, which in turn is directly related to the relative humidity.

From the above, it may be concluded that condensation nuclei are far more

* Giving rise to nuclei.

important factors in present-day smog problems than are neutral particulates. This is based on their greater relative number, far greater effectiveness in smog production, greater airborne potentialities, and more severe biologic effects.

Case of Community Air Pollution

Nonoccupational beryllosis (*6*). An incident of industrial environmental poisoning of unusual character, in which smog is not believed to have played a particular part, occurred in the vicinity of a beryllium plant. This situation in which 11 cases of chronic pulmonary granulomatosis developed was unique because the air pollutants, beryllium dust and fume, were in the atmosphere in extremely minute quantities. The study made was exceptional in that it is among the first to show a good correlation between the air concentration of the toxic agent and the distribution of cases about the source.

Cases of beryllium poisoning began appearing in the vicinity of the beryllium plant late in 1947. The arresting fact that eventually led to a full-scale community health examination was that the cases occurred with greater incidence in the neighborhood of the plant (1% of residents within ¼ mile) than within the plant itself (0.3% of employees). Among none of the cases under discussion was there a history of occupational exposure to beryllium and inasmuch as the plant was situated in a community of approximately 50,000 people, a real possibility of considerable hazard existed. The relationship of the plant operation to these cases was accordingly made the subject of an extensive investigation.

It was essential first to rule out all unrelated cases of pulmonary involvement (of which there were approximately 30), a matter requiring the attention of specialists in beryllium poisoning. Cases of chronic berylliosis were thus established only by concensus of experts. In this manner, a total of 9 cases were identified by early 1948. Five of these have ended fatally. Plant management requested the State Board of Health to arrange for X-ray chest examinations of a significant sample of the population. Of approximately 10,000 individuals who were X-rayed, 600 with possible pulmonary pathology were re-X-rayed. Questionable cases in this group, of which there were 12, were examined clinically in detail, and out of this group 3 new cases were discovered. One of the cases is excluded from the present discussion because it was found on further investigation not to have had an atmospheric

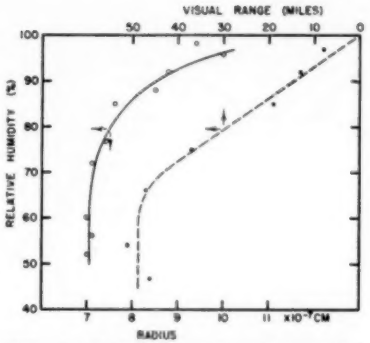

FIG. 1. Radii of condensation nuclei and average visual range as a function of relative humidity (arrows indicate direction of coordinates)

TABLE 2

Sulfur Content of Air and Average Number of Nuclei in Representative U. S. Cities

Sulfur $\mu g/m^3$	*Nuclei*/mm^3
0– 50	150
51–100	217
101–150	231
150	316

Beryllium is the fourth lightest element, with an atomic weight of 9.02. Since the 1920's in this country beryllium has been used in alloys with nickel, aluminum, and copper for many purposes because of its great lightness and resistance to stress and heat. In the late 1930's, scientists developed a powder containing zinc, manganese, and silica, as well as beryllium, which fluoresced when exposed to ultraviolet light. From this grew the huge fluorescent lamp industry. During the war, beryllium was used in many ways, especially as an alloy with steel in engines. Physicists, knowing that beryllium emits neutrons when bombarded with alpha particles, used this element as a tool in atomic energy research. Perhaps the greatest potential use is as a moderating material in nuclear reactors.

—*Harriet L. Hardy, Massachusetts Institute of Technology,* from "*Acute and Chronic Beryllium Poisoning,*" AECU-569

exposure but in all probability to have developed beryllium poisoning through the dust carried home in a worker's overalls.

The arrangement of the cases radially from the plant site showed a most interesting distribution (Table 3). Within ¼ mile of the plant, in which it was estimated that about 500 individuals resided, 5 cases were located, making an approximate incidence of 1%. Although no census was taken of the areas lying out of this section within the next ½-mile radius, only 6 additional cases were found and no cases were found at a distance greater than ¾ of a mile from the plant. Accordingly, the ecology of this problem was based on the fact that all known cases resided within this ¾-mile limit for a significant time when the beryllium plant was in operation.

TABLE 3

Incidence of Beryllium Cases Relative to the Distance from Plant

Distance from Plant	*Number of Cases*
0 to ¼ mile	5
¼ to ½ mile	4
½ to ¾ mile	2
¾ to 1 mile	0
1 to 1½ mile	0

Methods of investigation. Two methods were used for procuring data of the environmental atmospheric contamination by beryllium. One method reported concentration measurements downwind from the plant through collection of samples from a vehicle equipped with power supply that operated sampling equipment. The second type of data was collected from installed, fixed monitoring stations that were in operation continuously 24 hours daily. All samples were collected on Whatman #41 filter paper at a flow rate of 100 linear feet per minute and analyzed for beryllium spectrographically.

Decrease in beryllium air contamination downward from the plant during "present" normal operating conditions was measured according to the first method described. Observations were made at 8 locations over a distance of ¼ mile to 20 miles, and the data were plotted logarithmically as shown in Fig. 2. The average concentration of beryllium in the air at ¼ mile from the plant was 0.2 $\mu g/m^3$ with successively lower values at increasing distances from the plant until at 10 and 20 miles distant, less than 0.001 μg Be/m^3 was obtained, the limit detectable by the methods of sampling and analysis. Similar data were collected for 10 weeks according to the second method of continuously operating fixed monitoring stations within the radius of ¼ mile;

these yielded values consistent with the results sampled at greater distances. Extreme ranges of concentration were from 0–2.1 μg Be/m³ at 350 feet from the plant to 0–0.28 μg Be/m³ at 750 ft.

Determination of past atmospheric contamination. Plant processes, although modified in certain respects during the past 7 years, have remained essentially unchanged in character. Examination of past plant records show that a factor of 2 would account for any differences arising in the past. The plant effluents are, as in the past, discharged in part from a 185-foot stack and from a number of smaller roof-top stacks approximately 33 feet above ground level.

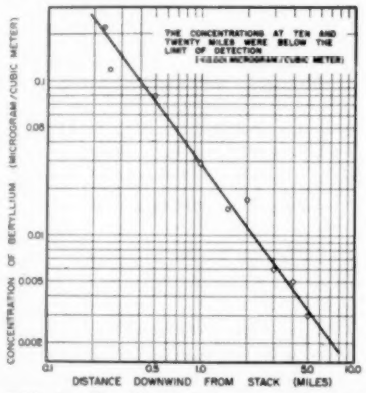

FIG. 2. Beryllium air concentrations at increasing distances from plant

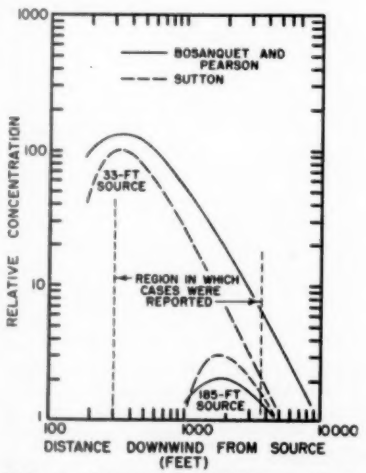

FIG. 3. Theoretical distribution of air contaminant at ground level for equal amounts of effluent at different stack heights

Utilizing the accepted expressions of Bosanquet and Pearson (*7*) and those of Sutton (*8*), the theoretical decrease of equal amounts of beryllium effluent was calculated for the average concentration at ground level, downwind on the axis of the effluent cloud originating from either the 185-foot or the 33-foot stacks. These calculations demonstrated that in all probability the 33-foot stacks make the more important contribution to the atmospheric contamination in a relation of about 30 to 1 at maximal average concentration. Thus a striking relationship is noticed between the fall-out of effluent originating at roof level and the distribution of cases. No such relation held for the 185-foot source (Fig. 3).

TABLE 4

Composition of Major Roof-Level Effluent in 1944

Compound	*Roof-Level Effluent gm/day*
BeO (BeCu fume)	2300
BeF_2	890
Beryl and beryl frit	300

Air contamination from beryllium plant processes. The compounds and their contribution to air contamination in 1944 are given in Table 4. These amounts may well have been of the order of 8-fold that in 1948, allowing a factor of 2 for less well-regulated stack-gas control during the earlier

period. Of these materials, beryllium oxide and beryllium fluoride are known to have produced a number of cases of beryllium poisoning; beryl, on the other hand, has rarely been implicated in cases of beryllium poisoning.

It is possible also that fluorine, a major component in certain of the processes and present inside the plant (*9*) in concentrations of from 100 to 1,000 times that of beryllium, should be added to the list of toxic contaminants. More recently, it has been shown experimentally (*10*) that fluoride is capable of doubling the toxic effects of beryllium exposure.

Inasmuch as no cases were discovered beyond the ¾-mile limit, it was of considerable interest to estimate the beryllium air concentration at that distance for the 1944 period to find some indication of the maximal concentration from which no disease occurs. This was done by using the methods of Bosanquet and Sutton previously referred to, employing the data obtained in the sampling test. Plots were made of the sum of the fall-out due to the 2,300 gm per day discharge from the 185-foot stack and the 1,200 gm from the 33-foot stack. Figure 4 shows these plots compared with plots of all samples (based on the assumptions of equal frequency in all wind directions and of an average wind speed of 10 miles per hour).

It is seen in Fig. 4 that the average concentration of beryllium at ¾ mile from the plant was between 0.004 and 0.02 $\mu g/m^3$, as determined during the 10-week, air-sampling period. Accordingly, a value of 0.01 $\mu g/m^3$ may be taken as a satisfactory approximation at this location during the period of study. Allowing a factor of 10 for a

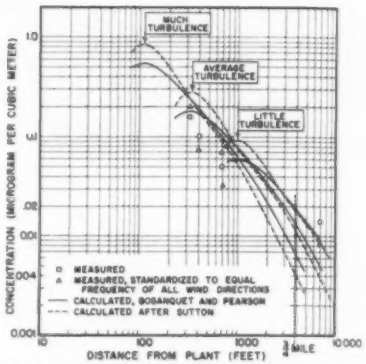

FIG. 4. Comparison of average beryllium air contamination (determined over 10-week period) with theoretical data

greater production during the period prior to 1948 and therefore greater amounts of roof-level effluent, it may be concluded *that the lowest concentration which produced beryllium disease was greater than* 0.01 $\mu g/m^3$ *and probably less than* 0.1 $\mu g/m^3$.

This conclusion, if true, is astounding, for no cases of community exposure to a chemically toxic agent at this concentration with concomittant cases of poisoning with fatalities are known. Thus, the foregoing represents a clear demonstration of cases of industrial poisoning in a community of ¾-mile radius in which the incidence of disease was proportional to the air concentration of the toxic agent. The conclusions give pause for thought that such minute concentrations as 0.1 to 0.01 $\mu g/m^3$ of an air-borne contaminant can produce, chemically, clinical disease with fatalities. It is worthwhile to note, also, that *protection for the worker within the plant does not insure community protection.*

IN-PLANT PROBLEMS

We turn to some cases of in-plant air pollution problems that illustrate recent developments in identifying toxic agents and in discovering special or peculiar particle characteristics responsible for hazard.

Physicochemical Solution of the Beryllium Oxide Problem

Possibly one of the most striking and best illustrative instances of particulate characteristics' playing a decisive role in industrial poisoning is the case of indoor-plant exposure to beryllium oxide dust.

Many grades of beryllium oxide of almost identical, high purity are manufactured by different companies by methods of preparation that differ in the starting materials, time and temperature of calcination. Industrial exposures to the oxide are similar in the different plants. Nevertheless, cases of beryllium poisoning, several terminating fatally, developed in a plant manufacturing the grade of oxide used ultimately for fluorescent-light manufacture, although the housekeeping in this plant was judged superior to that of other plants safely manufacturing other grades of oxide. The obvious question arose, "Were the cases the result of some peculiarity of these particular lots of oxide or were these instances of careless over-exposure?" The solution of this enigmatic situation represents a clear-cut example of the successful application of physicochemical methods to toxicologic problems.

The first approach was sought in possible differences in chemical composition of the oxide. Four different grades were examined, two refractory lots from one plant, one fluorescent grade from another and a fourth, a low-fired (400° C) preparation from a third plant, added for the purpose of furnishing a more extreme experimental case.

Analyses by chemical and spectrochemical methods showed a high purity approximating 97 to 100% BeO for all samples irrespective of their source, based on beryllium content. Moreover, no appreciable differences in impurities in any of the lots were found; impurities never exceeded more than 1% and were for the most part 0.05% or below. Obviously, differences in chemical composition furnished no clue to differences in toxicity. Furthermore, X-ray diffraction patterns presented no new information that controverted the chemical findings.

Concomittantly with the chemical studies, extensive studies by inhalation in animals were made. These showed the following results: (1) refractory grades, inappreciable toxicity; (2) fluorescent grade, evidence of toxicity at comparatively high levels of 90 mg/m³ characterized by weight loss in certain of the larger species (monkey and cat); (3) low-fired oxide killed approximately 30% of exposed rats at 90 mg/m³ and produced weight loss in this and other species exposed as well as other physiologic changes.

These distinct experimental differences in toxicity were consistent with the differences seen in industry. The order of toxicity, however, only roughly paralleled the firing temperatures at which the oxides were prepared. Some factors were yet undiscovered.

Physical methods including electron-micrograph studies and specific surface-area determinations combined with particle-size measurements were resorted to. These brought a most

It has been found that Beryllium is toxic to new orders of magnitude in comparison with Lead and Uranium:

	Amounts in Body Producing Toxicity
Lead	mg/gm tissue (0.001 gm/gm)
Uranium	μg/gm tissue (0.000,001 gm/gm)
Beryllium	mμg/gm tissue (0.000,000,001 gm/gm)

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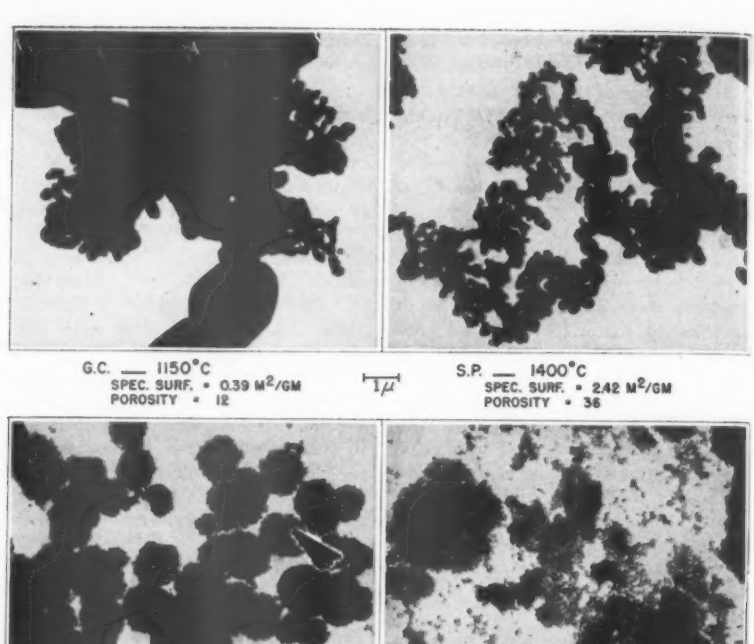

FIG. 5 Electronmicrographs of beryllium oxide of various grades (due to F. Bishop, S. Laskin, and K. Lauterbach, University of Rochester Atomic Energy Project)

satisfying revelation and offered almost incontestable evidence for the cause of the toxicologic differences. The four electronmicrographs shown in Fig. 5 display with ample clarity the marked differences in surface area of the different grades of oxide. "Porosity" values moreover (calculated as a ratio of the specific surface measured by inert gas absorption to the surface calculated from optical measurements of diameters) furnished data consistent with those obtained from surface-area measurements and the electronmicrographs. From the legends of Fig. 5, it can be noted that there was a 140-fold increase in specific surface from the G.C. grade to the low-fired oxide and nearly a 40-fold increase from the innocuous G.C. grade to the fluorescent grade which gave the first definite signs of toxicity in animals.

Preliminary data on the rate of solubility of 2 lots, the refractory and the 400° C material, were obtained on the basis that if great differences of surface area existed these should be reflected in greater rates of solubility for those

grades of oxide with the greater specific surface. Such was the case. Solubility measurements made at *p*H 7 in bicarbonate-citrate buffer showed at least a 25-fold greater rate of solubility for the oxide with the greater specific surface, a difference that correlates well with the differences in specific surfaces.

Thus there would appear to be ample evidence that the greater surface area (or some related property, *e.g.*, wettability, electric charge, *etc.*) of the insoluble oxide particles is responsible for the toxicity differences among the different lots of oxide. Increased surface area ordinarily is associated with decreased particle size, but not necessarily. The size of these solid particles that proved toxic are of the same order of magnitude as that of the SO_2 condensation nuclei that were likewise toxic. From such widely different materials, one could reasonably surmise that toxicity for animal tissues bears some fundamental relation to a *limiting* surface and particle size.

It is highly instructive to note that particle-size measurements by *optical methods* would not have revealed the key relationships nor have explained the toxicologic differences. With the exception of one of the refractory grades which had a particle size approximating 20 μ, no differences in the particle size of the other grades were found; the rest approximated 3 μ in diameter owing to aggregation. No more revealing were the specific gravities which showed only slight variation among the grades, from 2.78 to 3.04.

Factors Modifying Industrial Exposures

In addition to exposures to beryllium oxide dust, toxic exposures to a beryllium mist may exist. Such atmospheres contain fine particles of the order of 1 μ and smaller. The sulfate of beryllium, being soluble and highly acidic, is both irritating and toxic, as shown experimentally (*11*). In and about the sulfating processes where sulfuric acid is added to beryllium oxide and in the centrifuging operation of the resultant product, cases of industrial poisoning have resulted.

The purpose here is not to describe the nature of beryllium sulfate poisoning arising from inhalation of fine particulate mists but rather to emphasize another aspect of industrial exposures that will certainly become the subject of more intensive scrutiny in the future, namely, the effect of concomitant factors that may potentiate or otherwise modify the main toxic response. Actually, few industrial exposures are pure, most represent mixtures of potentially toxic agents or are complicated in other ways by physiological stresses such as hard physical exertion. Personal attributes such as age, sex, and nutritional disturbances may play a part in the over-all toxic response. Little information on mixed exposures is available and no maximal allowable concentrations (MAC) have been set for mixtures of toxic agents.

Enhancing Effect of Hydrogen Fluoride on Beryllium Poisoning

In view of the recognized prevalence of hydrogen fluoride and other fluorides in the vicinity of certain beryllium-plant processes (*9*), a study was performed in animals to determine whether this potentially toxic agent (fluoride) might exacerbate beryllium symptoms. Such a finding would furnish an insight into the factors that contribute to the onset or to the intensity of the disease.

Both beryllium sulfate mist and hydrogen fluoride vapor were administered by inhalation separately on alternate days to rats (*10*). The dosage of beryllium sulfate was such as to produce an LD-50* but that of the hydrogen fluoride was such as to be

* The dose that kills on the average 50% of the animals.

without any effect whatsoever on the species used. After 30 days of exposure the toxic effects of beryllium sulfate mist were found to have been doubled by the addition of concentrations of hydrogen fluoride that were absolutely without effect in the control animals when inhaled alone. This was shown by mortality rates, growth depression, and histologic examination of the lungs of the exposed groups.

This study with entirely consistent results among the various animal groups presents a clear demonstration of the manner in which one agent administered in subminimally toxic amounts may modify the response of another toxic agent. These results illustrate one of the first studies of its kind and are recorded chiefly to direct attention to the necessity of defining more completely the industrial atmosphere to which workmen are exposed.

Effect of Physical Exercise and Tuberculosis on Beryllium Poisoning

One of the dominant aspects of beryllium disease being its respiratory involvement (another being generalized disturbances in nitrogen metabolism), it appeared reasonable to assume that any factor that would tax the respiratory system would act unfavorably on the outcome of beryllium exposure. Cases both practical and experimental have been observed to bear this out.

A practical instance occurred in a large enclosed space in a plant where beryllium fluoride fume was accidentally liberated at a concentration believed from extrapolations of "on-the-spot" analyses to be 45 $\mu g/m^3$. In this area 7 individuals were present; 3 were engaged in moderately hard labor at considerable distance from the site of mishap; 4 were standing close to the site of mishap but performing no work. The interesting aspect of the accidental exposure was that the 3 working individuals shortly came down with cases of beryllium poisoning; no symptoms developed in the others.

This "on-the-spot" industrial finding was later verified experimentally in animals. Hamsters were exposed daily in two groups to a concentration of beryllium sulfate producing under normal exposure conditions little or no mortality. One of the groups, however, was subjected to exercise intermittently for $\frac{1}{3}$ of the time during the daily exposures. In this exercised group, 100% mortality occurred as compared with 12% in those hamsters similarly exposed but not exercised, thus demonstrating the enhancing effect of physical exertion on industrial beryllium poisoning.

In an extended study of more than one year's duration, it was found that the course of beryllium poisoning in guinea pigs exposed to beryllium sulfate mist by inhalation was not adversely affected by a preceding infection with tubercle bacilli nor conversely was the course of tuberculosis affected by the exposure to beryllium. In conformity with this experimental conclusion, it is the concensus of industrial physicians familiar with the beryllium problem that tuberculosis does not predispose individuals to beryllium poisoning nor beryllium poisoning lead to tuberculosis, thus differentiating beryllium disease from silicosis in which there is a distinct interplay of the two diseases.

HEALTH PROBLEMS IN URANIUM INDUSTRY

Because of early, keen appreciation of potential medical problems arising from widespread industrial use of uranium, probably no other element has been so thoroughly investigated from a pharmacologic and toxicologic aspect (*12, 13*). As a result, two major sites of possible radiation injury from long-

term inhalation of uranium dust in very low concentrations have been delineated: (1) lungs, from accumulation of insoluble uranium compounds; (2) bone, chiefly from accumulation of soluble uranium compounds, although insoluble compounds may be involved.

Unlike acute uranium poisoning where the kidney is the organ chiefly injured by chemical toxicity, the problem from chronic exposure is considered rather to be one of radiation. These deductions are based chiefly on one and two-year studies in which animals were exposed daily to either soluble or insoluble uranium dusts of accurately measured concentration and particle size.

Insoluble Compounds

For an insoluble compound such as UO_2 (naturally occurring isotopic mixture), the lung is the principal site of U deposition. Actual values determined for uranium in the lung of dogs and rats exposed for one year at 10 and 1 mg U per m^3 were extrapolated to lung uranium concentrations equivalent to the accepted uranium tolerance* for tissue, considering uranium as an internal alpha emitter. The calculated value of 25 μg U per gm of fresh tissue is based on a radiation tolerance of 0.05 rep. From this, a tentative maximal allowable concentration (MAC)† for insoluble, naturally occurring, inhaled uranium compounds (such as UO_2, U_3O_8, "high-grade" U ores and with less certainty, UF_4) was set as 100 μg U per m^3 of air on a radiation basis. Included in this value is a safety factor of from 2–5 fold. Solely on a *chemical toxicity* basis, the suggested MAC was significantly larger, being 200–250 μg U per m^3 with reasonable safety margins.

The above-quoted MAC's were based on dusts with mass-median particle sizes of approximately 1 μ, but lung retention of insoluble uranium dusts have been shown in 30-day studies to be greatly influenced by particle size. Appreciation of this is given by the finding of an average lung content of more than 1200 μg U per gm from 0.5 μ particles, whereas only 150 μg U per gm were retained in the lung at the larger size of 2 μ inhaled at the same concentration of 80 mg per m^3. From these results, MAC values should include a safety factor of 8 to allow for particle-size variation.

From the studies of animals breathing UO_2 dust for 1 year followed by uranium nitrate dust for a second year, the biologic half-life in the lung was calculated to be from 2–4 months. Thus a vacation or job transfer of an over-exposed individual for 2–4 months would reduce by 50% the UO_2 retained in the lung and thus increase the factor of safety in setting air-concentration tolerance levels.

Soluble Compounds

For the soluble compounds UO_2F_2 (from UF_6 exposures), U-nitrate, and UO_2Cl_2, $UOCl_2$ (from UCl_4 exposures), similar long-term exposure studies and calculations have been made; it was found, on the average, that the lung contains the least, the kidney intermediate amounts, and the bone the greatest amounts of uranium. Thus, in marked contrast to the finding with insoluble compounds, the bone is the predominant site of deposition. The predicted biologic half-life was found to be of the

* Tolerance as used here refers to the concentration (of U) that may be withstood indefinitely without producing demonstrable injury in practically all individuals.

† MAC refers to a value expressing the air concentration of a potentially injurious substance which may be taken into the body by inhalation for an indefinitely long period without the production of harmful symptoms in practically all individuals. These values are agreed upon yearly by a Committee on Threshold Limits and are usually accepted by the American Conference of Governmental Industrial Hygienists. An attempt is made to revise these values annually but this is not always done. In regard to their legality, they do not have the force of law but many states may and have adopted these values to support legal action.

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order of 10 months in bone. With increasing air concentration, there is a tendency toward increased uranium content of tissue.

Utilizing actual values for deposition found in animals inhaling soluble uranium dusts, it was found that the 25 μg U per gm tissue tolerance level (based on radioactivity consideration) would never be attained over any reasonable period under any industrial exposure condition. The MAC was thus tentatively set at 50 μg U per m^3 of air for soluble compounds purely on a chemical toxicity basis of renal injury.

BIBLIOGRAPHY

1. J. Shilen, *Ind. Med.* **18,** 71 (1949); also U. S. Public Health Bulletin 306 "Air Pollution in Donora, Pa." (Preliminary Report) (1949)
2. R. A. Kehoe, personal communication
3. H. F. Johnstone, *J. Ind. Hyg. Toxicol.* **30,** 358 (1948)
4. Paul L. Magill, *Ind. Eng. Chem.* **41,** 2476; also Louis C. McCabe, *et al., ibid.,* 2486 (1949)
5. H. Neuberger, *Mech. Eng.* **70,** 221 (1948)
6. M. Eisenbud, R. C. Wanta, C. Dustan, L. T. Steadman, W. B. Harris, B. S. Wolf, *J. Ind. Hyg. Toxicol.* **31,** 282 (1949)
7. C. L. Bosanquet, J. L. Pearson, *Trans. Faraday Soc.* (London) **32,** 249 (1936)
8. O. G. Sutton, *Quart. J. Roy. Met. Soc.* (London) **73,** 426 (1947)
9. H. C. Hodge, S. Laskin, H. E. Stokinger, Rochester Area Report M-1997 (1947)
10. H. E. Stokinger, N. J. Ashenburg, J. K. Scott, J. DeVoldre, F. A. Smith, Rochester Area Report UR-68 (1948)
11. H. E. Stokinger, G. F. Sprague, R. H. Hall, N. J. Ashenburg, J. K. Scott, *Arch. Ind. Hyg. Occup. Med.* (in press)
12. C. Voegtlin, H. C. Hodge, "The Pharmacology and Toxicology of Uranium Compounds," NNES VI-I (McGraw-Hill Book Co., Inc., New York, 1949)
13. *Ibid.*, "Chronic Inhalation and Other Studies" (in press)
14. N. R. Beers, NUCLEONICS **4,** No. 4, 28 (1949)
15. Symposium on Atmospheric Contamination and Purification (papers presented at 115th meeting of Amer. Chem. Soc.), *Ind. Eng. Chem.* **41,** 2383–2493 (1949)

EVEN IN LOW-LEVEL-ACTIVITY WORK, however, the most careful planning of each experiment is required to avoid radioactive contamination. If at all possible, a separate laboratory should be devoted exclusively to radioactivity work. When a new experiment is undertaken, it is almost always advisable to make a "dry run," that is, to go through the entire experiment using non-radioactive materials so that the procedure and apparatus, and particularly the disposal of waste, can be thoroughly checked.

While the problem of safeguarding personnel is paramount, cross-contamination of experiments by transfer of radioactivity from one area of the laboratory to another is considerably more difficult to avoid.

—Arthur D. Little, Inc., Cambridge, Mass.

Radiation-Exposure Survey of X-ray and Isotope Personnel

Analysis of a total of 7678 films worn by personnel in these two fields shows clearly that the X-ray worker received considerably more radiation exposure than the isotope worker

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WITH THE ADVENT of the atomic age and the increasing use of radioisotopes in laboratories, it has become necessary to have adequate protection against radiation and to have a check on the amount of exposure received by each individual. At the same time, roentgenologists have become more aware of the exposures encountered by X-ray workers and of the need to keep within the permissible (tolerance*) dose.

The permissible dosage rate as recommended in the National Bureau of Standards Handbook "Medical X-ray Protection up to Two Million Volts" (issued March 30, 1949) (*1*) is: "the maximum total dose to which any part of the body of a person shall be permitted to be exposed continuously or intermittently in a given time. It shall be 0.300 r per week. On the basis of 48 hours per week of uniform exposure, the permissible dosage rates are: 0.00625 r per hour (6.25 mr per hour)," *etc.*

In the Isotopes Branch Circular B-1 "General Rules and Procedures Concerning Radioactive Hazards," (issued August, 1947) (*2*), the maximum permissible dose for isotope workers is given as follows: "The tolerance level for total or limited body exposure is 0.1 rem (roentgen-equivalent-man)† in any 24-hour period. . . . It is advisable, however, to strive for the lowest possible daily total exposure in every operation."

In the survey‡ reported here, we were interested in how much radiation was received by X-ray workers, and how many radiation workers exceeded the permissible dose. The permissible dose recommended in the NBS handbook was used as a basis of comparison of radiation received by all radiation workers.

Several investigators (*3, 4, 5*) have used the principle of photographic blackening on film to measure radiation. The du Pont dental film 552-2 has been especially developed as an indicator for radiation. The film packet consisting of two films, one with a range of from 0 to 3 r, and the other, less sensitive, from 0 to 20 r is placed in a badge holder,

* *Editor's Note;* "Tolerance" is gradually being replaced by the expression "permissible dose" which more accurately describes the maximum exposure which the worker can take day to day without harmful effect.

† Roentgen-equivalent-man (rem) is defined as "that quantity of radiation which when absorbed by man produces an effect equivalent to the absorption by man of one roentgen of X or gamma radiation" (*2*).

‡ This work was done in part under contract from the Office of Naval Research and the Atomic Energy Commission.

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TABLE 1
Nine-Month Survey of Films Worn by X-Ray Personnel
Total number of films exposed—2655

Roentgen values	*Number of films in each group*	*% of films exposed*
0–0.049	2568	97
0.05–0.099	50	19
0.1–0.199	18	0.68
0.2–0.299	8	0.30
0.3–0.399	3	0.11
0.4–0.499	5	0.20
0.5–0.599	1	0.04
0.6–0.699	1	0.04
0.7–0.799	1	0.04

and worn for a week by radiation workers either on the lapel or outside of the laboratory coat so that the maximum amount of total body exposure is indicated on the film. The films are developed by a standard procedure (*6*), and the densities, read on an Ansco-Sweet Densitometer, are correlated with roentgens from established curves (*6*) of density vs roentgen values.

A survey was made of developed films from a number of X-ray departments and isotope laboratories. It must be pointed out here that though the following statistics present an average picture of radiation workers, it is the individual worker who receives excessive exposure that we are most concerned about. Our figures are for total body radiation; local radiation in some cases, *e.g.*, hands, may be considerably higher and in excess of the permissible dose.

Films were worn by 45 persons in four X-ray departments over a period of nine months. Table 1 presents an analysis of the number of films exposed with the percentages of films in various roentgen groups.

Eleven films showed exposures greater than the permissible dose. Four workers of the 45, or 9%, received these 11 exposures. One fluoroscopist received exposures greater than permissible dose five times during this period, with two exposures following in consecutive weeks. The film for one of these weeks showed multiple exposures totaling 0.42 r while the film for the other week indicated evidences of a single exposure of 0.53 r. Another worker showed films with exposures of 0.6 r and 0.7 r. Subsequent investigation revealed that this individual is a dental technician. Of the persons in the survey, one other individual received two exposures greater than the permissible dose.

A representative picture of radiation received is given by the same type of survey carried out in 13 establishments with 61 persons in the program for a period of 3 weeks. For the first week individuals are careful about receiving excessive exposures, in the second week they become careless, and in the third week they follow their regular routine. The survey includes doctors' and dentists' offices and X-ray departments. Table 2 presents an analysis of films exposed.

TABLE 2
Three-Week Survey of Films Worn by X-Ray Personnel
Total number of films exposed—183

Roentgen values	*Number of films in each group*	*% of films exposed*
0–0.049	149	81.5
0.05–0.099	13	7.1
0.1–0.199	11	6.0
0.2–0.299	3	1.6
0.3–0.399	0	0
0.4–0.499	1	0.54
0.5–0.599	2	1.1
4	1	0.54
5	1	0.54
9	1	0.54

TABLE 3
Eight-Month Survey of Films Worn by Radioisotope Personnel
Total number of films exposed—4840

Roentgen values	*Number of films in each group*	*% of films exposed*
0–0.049	4716	98
0.05–0.099	6	0.12
0.1–0.199	7	0.15
0.2–0.299	6	0.12
0.3–0.399	1	0.02
Chemical fog	4	0.08

Over the three-week period, six films indicated radiation above permissible-dose level. The excessively high exposures of 4 r, 5 r, and 9 r were received by the same urologist for three consecutive weeks. The survey includes one industrial establishment with 15 people where 0.14 r was the highest exposure in the group. Recently a South American hospital has become interested in the program, and from this hospital no exposure greater than 0.05 r has been registered. Data indicate that the establishments vary considerably in the amount of radiation received. Films from one particular hospital show over a period of six weeks exposures which are consistently high. Two of the nine workers, or 22%, showed exposures greater than 0.3 r, while 55% showed exposures greater than 0.15 r but less than 0.3 r.

A similar survey of isotope laboratories over a period of eight months with 140 individuals in the program was carried out. The following isotopes were used by the workers: Na^{24}, I^{131}, Zn^{65}, Fe^{55}, S^{35}, C^{14}, Sr^{90} in equilibrium with Y^{90}, Cs^{134}, Co^{60}, Ca^{45}, P^{32}, Be^{7}, A^{37}, Cr^{51} and Ra. An examination of the energies of the various isotopes reveals that most of them approximate the energies of the established curves (*6*) so that these curves may be substituted for the various isotopes. By use of the range-energy relation for beta particles (*7*), it has been calculated that the wrapping paper on the dental film is such a thickness and density as to cut out all radiation below 0.15 Mev. Table 3 is similar to Tables 1 and 2.

Only one individual in the isotope laboratories as contrasted with 9 in X-ray departments received an exposure greater than 0.3 r, and this, only 0.31 r. Another individual received over a period of five weeks three exposures of greater than 0.1 r but less than 0.3 r from Sr^{90} in equilibrium with Y^{90}.

One film was so black that it was not readable on the densitometer. Investigation revealed than an I^{131}-organic extraction had been performed and the blackening was probably due to chemical fog. It has been previously established that certain chemicals fog film (*6*). It must be pointed out here that if fog is heavy, distinction between radiation and chemical fog would be difficult to make.

As part of the survey, several individuals in one laboratory wore films on their hands and wrists in an attempt to see how much exposure they received in opening radioactive shipments as they arrived from Oak Ridge. One individual would open weekly a unit* of Na^{24} of approximately 20 mc; biweekly a unit of K^{42} about 130 mc, a unit of P^{32} about 50 mc, and occasionally one unit of Ca^{45} about 0.8 mc; and monthly or so about 30 mc of I^{131}. Even though the amount of radiation which emanates from the radioactive container while being opened is considerable, no exposures were indicated on the film. The procedure of working at a maximum practical distance from the

* The millicurie values stated for each shipment of radioisotopes are those found in the Radioisotopes Catalog, but when the shipment is opened the activity dependent upon the half-life of the isotope of the particular isotope may vary considerably from the catalog figure.

radioactivity, of using especially developed equipment and of performing all operations in a minimum time keeps the exposure down to a minimum.

From the data presented for both X-ray workers and isotope workers, it may easily be seen that the X-ray worker receives considerably more exposure than the isotope worker who in this survey rarely ever approaches the permissible-dose level. Data on the isotope workers are in good agreement with the figures reported from Hanford Works (*8*).

BIBLIOGRAPHY

1. "Medical X-ray Protection up to Two Million Volts," National Bureau of Standards Handbook 41, page 1. (U. S. Government Printing Office, Washington 25, D. C., 1949)
2. "General Rules and Procedures Concerning Radioactive Hazards," U. S. Atomic Energy Commission Isotopes Branch Circular B-1, page 1 (August, 1947); see NUCLEONICS **1**, No. 4, 60 (1947)
3. G. E. Bell. Photographic action of X-rays, *Brit. J. Radiology* **9**, 578 (1936)
4. G. Failla. Radium protection, *Radiology* **19**, 12 (1932)
5. R. B. Wilsey. Photographic photometry of Roentgen rays, *Am. J. Roentgenol.* **32**, 789 (1934)
6. R. F. Cowing, C. K. Spalding. Photographic effect of various radiations on special dental packets, *Radiology* **52**, 423 (1949)
7. R. E. Lapp, H. L. Andrews. "Nuclear Radiation Physics," page 180 (Prentice-Hall, Inc., New York, 1948)
8. "Sixth Semiannual Report of the Atomic Energy Commission," page 58 (U. S. Government Printing Office, Washington 25, D. C.; 1949)

Engineering Opportunities in Atomic Energy*

The author, a prominent nuclear scientist, calls the atomic energy field the most stable in America, as far as employment is concerned. The existing need for engineers is detailed

By L. B. BORST

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"GO WEST, young man, go west" was the famous injunction of a famous editor of the past century. At the midpoint of the twentieth century we no longer have a geographical frontier. The question for us to analyze is whether the twentieth century frontier lies in technical directions and, for the present discussion, particularly whether atomic energy constitutes a segment of this frontier.

Let us examine the nature and extent of the present atomic industry. The Congressional appropriation for the present fiscal year is $750 million. These funds are used by the United States Atomic Energy Commission. In addition the armed services are allocating significant funds to specific atomic energy problems.

In this field labor constitutes the principal cost, with the number of

* From talk presented at a meeting of the American Society for Engineering Education at Kansas City, Mo., on October 28.

persons employed directly or indirectly being about 200,000. Because of the diverse varieties of skills represented it is difficult to estimate accurately the number of technical personnel. The highly technical nature of the total effort certainly implies an unusually high ratio of scientific and engineering talent. It is probable that more than one in every fifty persons deriving employment from the AEC has scientific or engineering training. Considering equal numbers of engineers and scientists, we therefore obtain a total engineering personnel of 2,000 employed on AEC funds at the present time. Under present conditions this is certainly a low estimate since construction comprises a large fraction of AEC activities for the present year. If 30 years is assumed as the average technical life of an engineer, then the long term rate of replacement will be 70 per year.

At the present time the number being employed per year is much larger, due to the building up of various specific programs.

While there is a real and urgent need for men trained in this field, there is no adequate existing source of such engineers.

It is apparent from the foregoing that nuclear engineering has the potentialities of a stable market which, while not large in comparison with many consumers goods industries, is nevertheless significant.

Nature of Nuclear Engineering

What is nuclear engineering? Perhaps it is as diversified as all the various specialties of engineering. Let us examine the various existing installations for insight into its many ramifications.

First there is the Los Alamos Scientific Laboratory which is devoted to the production and improvement of weapons. Meticulous chemical processes prepare the materials which are costly and deadly. Precision parts are fabricated by novel means. Experiments are conducted which require a highly coordinated organization, and in which great care must be exercised. In all this work the possibility of accidents must be minimized, and the protection of personnel must always be the first consideration.

The Armed Services, whose responsibility it is to develop means of delivering the weapon, and who must understand its properties and uses, have work in progress at several locations.

Plutonium Production

The General Electric Company operates the plutonium production plant at Richland, Washington. This is a process industry in which the operating and maintenance engineer and the production man will find most scope. The production of the plutonium in a reactor while involving a nuclear transformation, usually thought to be a subtle process of nuclear physics, has the atmosphere of a water treatment plant, or an oil refinery. Chemical separation and purification of the plutonium, carried out by remote control, is an exceedingly elaborate and tricky operation requiring ingenuity on the part of the operating staff.

At Oak Ridge the Carbide and Carbon Chemicals Corporation operates the gaseous diffusion plant. This is perhaps the largest and most complicated continuous flow project in history. Here again the cost-minded operating or maintenance engineer is in his glory.

The Argonne National Laboratory and the Oak Ridge National Laboratory do not have routine production commitments beyond the preparation of exotic and unusual isotopes for use in research and medicine. Their other functions are development and research. The AEC has centered reactor

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development at Argonne. An extensive design and development organization is forming which will have as much as it can handle to design and execute the various reactors presently planned. There is ample opportunity here for the design engineer, and for the man with novel ideas.

The Knolls Atomic Power Laboratory of the General Electric Company, as its name implies, is responsible for the development of future power reactors. Here again there is opportunity for men of many specialties who have imagination.

Brookhaven National Laboratory is dedicated primarily to fundamental research upon which may be built future technology. While most of the laboratory is devoted to the usual scientific disciplines—physics, chemistry, biology and medicine—the group now supervising the construction and initial operation of the reactor will devote its time in the future to the study of some of the more fundamental obstacles confronting the reactor field.

Both at Brookhaven and at Berkeley, California, billion-volt accelerators are under construction. It is in this direction that most scientists expect revolutionary nuclear discoveries to lie. Yet even in these pioneering ventures the mechanical, and much of the electrical, design is in the hands of engineers.

Work in Private Industry

The foregoing discussion has been devoted to the Atomic Energy Commission installations. Other smaller organizations abound, devoted to various specialized objectives in which engineering plays a greater or lesser role. Certain parts of the over-all program are carried out within the sphere of private enterprise with little or no government supervision.

The mining of uranium and the concentration of the ore are carried out in as free a fashion as the law will permit. Colorado is the principal site of uranium mining, though prospecting is probably carried out in every state of the Union. The mining engineer can perhaps find his place in the over-all program with less adjustment than any other engineering specialist.

There is a great need for the development of reasonably economical methods for concentrating low-grade ores, found in abundance in many states. Such investigations could be conducted in university laboratories just as well as in AEC installations.

A large variety of industries participate in the general AEC program to a greater or lesser degree. The uranium is purified and prepared in usable form in a long sequence of industrial operations. While materials control and ascending degrees of security must be applied, the general framework is industrial in the normal sense.

Need for Special Materials

Special materials are required in different phases of development. Beryllium is often considered for use as a moderator in a reactor. The availability of beryllium in the requisite amount and purity is always a limiting factor for the design engineer. Up to the present time we have found no magic structural metal or alloy which has a reasonable strength at elevated temperatures, resists corrosion under operating conditions, and yet has a low neutron-capture cross section. Several rare metals are being prepared and tested, and from these the future design engineer must choose. Several university and industrial laboratories are participating in this work.

Gadgets and mechanical or electrical devices are required of an almost unending variety: special valves, pumps with no moving parts, unusual welding

machines, filters, automatons by the dozens, to name a few. In most cases, the AEC endeavors to develop industrial sources for such components if they can be found or their development stimulated.

Radiation detection instruments are sufficiently important to be treated separately. In all nuclear work, instrumentation is of paramount importance. Since radiation gives no stimulus to any of the senses, instruments must take their place. The inventory of specialized instruments at an atomic laboratory is truly impressive. Radiation instruments have been declassified as a field to stimulate commercial development. Here is a real opportunity for inventive genius. Even now, though we use them by the thousands, we have no truly satisfactory personnel monitoring instruments.

"Atomic Age"

As important perhaps as all the foregoing is the phase of the field which is often talked of as the "atomic age"—the application of our knowledge of nuclear phenomena to medicine and particularly to industry. It is the most diversified and most promising, as well as the least developed. At the present time a very few industrial applications are developing; for instance, a thickness gauge for measuring thin films. Similar to it is a liquid level indicator which consists merely of an instrument held near the exterior of the vessel.

The use of isotopes for research has often been discussed and, without question, has the most profound implications. The use of isotopes for analysis, process control and other normal industrial purposes has been slow in developing mainly because of a lack of trained persons able to see nuclear solutions to industrial problems.

I have absolute faith that the much talked of "atomic age" will come, and that the nucleus will find an important place in American industry. How rapidly this will occur will depend largely upon how rapidly trained personnel get into the field of industrial applications.

Historically the atomic energy field originated in academic laboratories. During the war, great national laboratories were established which were directed and supervised primarily by the trained scientists. Industries were brought in to work with the scientists to develop, construct and operate production plants. At the end of the war, most of the scientists returned to their pre-war fields. While it has always been assumed that the nuclear field would rapidly be turned over to industrial management, this transition has not, by any means, been complete. There has been a gap yet unfilled between the scientist-engineer teams of the war, and the long term industrial organization. The difficulty is that the really good scientists have returned to their pioneering, leaving the field to their less skilled brothers and to engineers with inadequate scientific background. The more rapidly the engineering profession can overcome its weaknesses, the more rapidly the field can advance.

Most Stable Field

The engineering student may properly ask, "This is all very well but is there a stable future in this field?" My answer would be that there is no more stable field in America. The present effort is guaranteed by the present international situation. Increased international tension will certainly bring increased effort. If international tensions relax, then several new possibilities exist. If international control becomes a reality, the control agency will require technically trained personnel. Who knows, atomic energy might even be included in President

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Truman's point four program calling for the technical development of backward countries. With relaxed international tensions will certainly come relaxing of security, permitting increased industrial development of the field.

Security is an ever present cloud over the whole field. By security is meant, of course, the restriction of information, the checking of personnel by the FBI, the review of information before publication, *etc.* Security as we all know, is a necessary corollary of the present international situation, and will respond to changes as they occur.

The national importance of adequate development of this field cannot be overstressed. If we are to compete favorably with other nations we must give our best, for nothing less will do. We have seen recently that competing nations cannot be ignored. In spite of all statements from Washington, their progress has been unexpectedly rapid. We no longer can piously say that we are better than the rest of the world, and that we are safe for ten to twenty years. In this atomic race, as in looking-glass-land, we must run to stay where we are, and must run very hard to get ahead.

Many Unsolved Problems

When we take an over-all view of the field we see vast unsolved problems in every direction. Can we breed fissionable materials? Can we produce power to compete with coal? What will we do with the atomic ashes from our furnaces that stay "hot" for centuries? How can we keep from contaminating our planet? Can we build an atomic-powered airplane?

Of course these questions have all been resolved in the Sunday supplement, and they constitute no problem to the comic strip artists. But there are some of us who must do these things to whom they do not seem simple.

In this field there is the challenge of unexplored technical lands. Just as the early American pioneers visualized better land beyond each barrier, we see great rewards beyond each obstacle.

The obstacles we see are not subject to incremental attack. We cannot simply improve efficiencies by raising temperatures or pressures. They are fundamental, and cannot be solved with the aid of engineering handbooks. The problems must be attacked from first principles. The solutions to be found are unorthodox by normal engineering criteria, and come from the technical innovator who has a broad fundamental background. We need technical pioneering.

It is unfortunately true that the person of great ability will probably not receive the same monetary reward he would receive in private enterprise. It is doubtful if great fortunes will be made in this field. Development up to the present time has been at the expense of the people, and Congress has justly decided that there shall be no exploitation. Of particular importance in this regard is the government ownership of patents.

We find here the anomaly of all government. We need the most able people in the nation, for if the future is dark, national survival may be at stake, yet the restrictions inherent in the work—security and remuneration—tend to drive away the most capable, and the most needed persons.

Nuclear engineering constitutes one of our technical frontiers. It is a young, vigorous, agressive field. Its future is certain. Atomic energy is a permanent and rapidly developing field. There are few limitations on the young man of ability for he can advance as rapidly as he is able. There is little stagnation of ideas. Any good idea will be pursued and exploited as rapidly as is consistent with the over-all program.

BOOKS

Isotopic Report: Tabular Survey of the Properties of Atomic Nuclei as Known until the End of 1948, by Josef Mattauch and Arnold Flammersfeld, in German and English, Verlag der *Zeitschrift für Naturforschung*, Tübingen, Germany, 1949; 244 pages; paper binding, 30 marks; linen binding, 35 marks. *Reviewed by K. Way and L. Fano, National Bureau of Standards.*

In the nuclear field no far-reaching systematizing principles have yet been discovered. Only a few empirical rules are known to guide the nuclear physicist or engineer through the maze of data now available for over a thousand nuclei. For this reason systematic collections of all the relevant information are essential for all users of isotopes. Such collections also provide theoretical students with indispensable tools in the search for new regularities and correlations.

The new Mattauch-Flammersfeld "Isotopic Report" containing all information available at the end of 1948 is the most up-to-date and comprehensive nuclear data collection available at present. As everyone would expect from these authors, their report is an outstanding work. Actually it is much more than a collection since it lists the present "best values," in the authors' estimation, of all nuclear quantities for which measurements are available.

It is easy to convince oneself that the immense job of evaluating critically a mass of often conflicting results has been done judiciously and painstakingly. One has only to start reading the papers on certain elements notorious for conflicting results, such as Pt, Mo, and Sb to assure oneself that very strong arguments can be made for the "best values" given in the Report. Of course, not all readers will arrive at conclusions identical with those of Mattauch and Flammersfeld, but they will enjoy the imaginary arguments that will arise in the course of defending any differences.

In addition to listing the "best values" with the appropriate references, Mattauch and Flammersfeld give all other available references for each nuclear property without listing all the results. Their system makes an extensive literature search easy and quick. Seaborg and Perlman in their "Table of Isotopes" give several of the more recent values for each property. This method makes it possible for the reader to get an idea of the extent of agreement fairly quickly, or to find at a glance places where discrepancies exist. Thus, the student looking for conflicting results which call for further investigation might turn first to Seaborg and Perlman, while one who wanted to make a thorough study of all the work on a particular isotope would find better help from Mattauch and Flammersfeld.

Perhaps the best way to give an idea of the content and scope of the Report is to compare it further to the Seaborg-Perlman Table of Isotopes which is familiar to most American workers in the nuclear field.

For radioactive nuclei the main table of Mattauch and Flammersfeld gives information on half-lives, modes of decay, particle and quantum energies, methods of production, and includes a certainty rating very much as do Seaborg and Perlman. In addition, it lists the total decay energy when this has been determined by coincidence or spectrometric methods. This is a very helpful figure, but unfortunately it is available only in an extremely small number of cases.

For stable nuclei Seaborg and Perlman give only the relative abundance,

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while Mattauch and Flammersfeld give, in addition, values for spins, magnetic moments, and quadrupole moments where these have been measured.

For elements through argon they also list masses from a new computation of isotopic weights from measurements of mass-spectrographic doublets, reaction energies, and decay energies. An account of this computation is to be published by one of the authors separately. The neutron and proton masses used are 1.008939 and 1.0081297, respectively, giving a neutron-proton mass difference of 753 kev.

In a supplementary table Mattauch and Flammersfeld give 85 diagrammatic decay schemes. These schemes, though very helpful, do not always show complete agreement with the values of the main table. Other auxiliary tables list mass-spectrographic measurements, reaction energies (Q values) and thermal neutron activation cross sections.

There are natural differences in the emphasis placed on different material by the European and American compilers. Seaborg and Perlman have been able to evaluate and report the results of Manhattan Project work, a good deal of which has not yet been published. Their tables were made available to the German compilers before the latter went to press, and thus a good many project results listed by Seaborg and Perlman are also given by Mattauch and Flammersfeld. However, since the latter have no knowledge of the experimental work on which the results are based, they naturally handle them rather gingerly. Publication of the radiochemists' project volumes should help to remedy this unfortunate situation.

Mattauch and Flammersfeld seem to have a more complete coverage of the European literature than the American compilers. This superiority is especially marked in the case of naturally radioactive nuclei where most of the data are contained in the older European journals.

It is only to be expected that any big compilation contains a few misprints and errors, but quite extensive use of the Mattauch and Flammersfeld report has revealed surprisingly few. Nuclear physicists can make use of this report with great confidence, and we feel sure they will join us in admiration and gratitude for the outstanding job that has been done.

[*Editor's Note:* For other details (of an informative rather than critical nature) of the Mattauch-Flammersfeld "Isotopic Report," see NUCLEONICS **5**, No. 2, 70 (1949).]

Ionization Chambers and Counters: Experimental Techniques, (Div. V, Vol. 2 of National Nuclear Energy Series), by Bruno Rossi and Hans H. Staub, McGraw-Hill Book Co., New York, 1949, 243 pages, $2.25. *Reviewed by J. B. H. Kuper, Instrumentation and Health Physics Dept, Brookhaven National Laboratory.*

This volume, one of the three books on experimental techniques developed during the war at the Los Alamos Laboratory, will be of interest to anyone concerned with the design of ionization chambers or proportional counters. Although much of the information it contains on such important topics as electron collection in pulse ionization chambers has been carried to other laboratories by Los Alamos alumni, it is most helpful to have the subject treated in an orderly, connected fashion.

The book is divided into two parts. The first four chapters treat the physical principles of ionization-chamber operation with special emphasis on topics concerned with pulse-detection techniques which have not been described elsewhere. Chapter 1 is concerned with the behavior of free electrons and ions in gases and particularly with the effect of gas composition on the drift velocities of electrons. The next two

chapters treat the operation of ionization chambers with constant and variable ionization, respectively, and Chapter 4 is devoted to the subject of gas multiplication.

The remaining five chapters discuss in detail a variety of detectors which were found useful at Los Alamos. Chapter 5 covers beta-ray, gamma-ray and X-ray detectors, of the integrating-ionization-chamber, Geiger-Müller, and pulsed-counter types. Chapter 6 is devoted to alpha-particle detection, with parallel plate and proportional counters. The final three chapters are devoted to the topic of neutron detection. Chambers for detecting neutron recoils are treated extensively in Chapter 7, and detectors employing the (n,α) and (n,p) reactions are discussed in Chapter 8. The ninth chapter takes up fission detectors of various types and gives considerable information on the details of their construction. In addition, there is an appendix in which a great deal of data useful in the design of ionization chambers, such as range-energy relations for various particles, gamma-ray absorption coefficients, and corrections for backscatter and dead-time, are assembled in handy form.

The authors are to be congratulated on the clarity with which they have handled their subject, and the book is relatively free of misprints. However, I noticed some discrepancies between Figs. 5.14 and 7.21 and their accompanying texts, and that several lines of text are transposed on page 227. Also, Fig. 3.13 appears to be reversed.

Some will be disappointed that the subject matter is confined so strictly to topics that were of special interest to the Los Alamos group, but the book otherwise could scarcely be a part of the National Nuclear Energy Series. It belongs on the "must" list of anyone who is concerned with the design or operation of ionization chambers, particularly pulse chambers.

Isotopic Tracers and Nuclear Radiations with Applications to Biology and Medicine, by William E. Siri with collaborators, McGraw-Hill Book Co., Inc., New York, 1949, xiii + 653 pages, $12.50. *Reviewed by Howard L. Andrews, Laboratory of Physical Biology, Experimental Biology and Medicine Institute, National Institutes of Health.*

This book was written to serve as a reference source to bridge the gap between the widely scattered research papers and presently available textbooks. It is described as "A Handbook of Theory and Practice in Nuclear Physics and Tracer Methodology" but it is much more than a handbook. Tables, graphs, and formulas are supplemented by extensive textual material and by liberal references to the original literature. The text lacks the logical sequence and development of a textbook, and this may make it difficult to use by those not familiar with the field. Particularly in Part I, *Isotopes and Nuclear Reactions,* results and equations are sometimes given with a finality which implies more rigor than is actually present.

Part II, *Methods and Instruments,* is an excellent discussion of techniques and apparatus. It is gratifying to find a thorough treatment of the techniques of stable-isotope assay along with radioactive-tracer methodology. One chapter is devoted to the safe handling of radioactive isotopes. It seems unfortunate that the chapter on radioautography in a book of a handbook type did not include quantitative data on emulsion sensitivities and resolving powers.

Biological and Medical Applications of Isotopes are discussed in Part III. Elements of possible significance to biology are treated in detail both for use as tracers or for therapy. One of the features of this section is the bibliography of nearly 1,800 items of tracer methods and results.

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Specific criticisms of any book are always of doubtful value because of the personal preferences of the reviewer. In view of the more usual meaning attached to it, it seems unfortunate that the term atomic weight was used for A, the total number of nucleons in the nucleus. There is also a disturbing lack of consistency among some of the numerical values listed. Within a space of two pages, S^{35} is listed with half-lives of 88 and 87.1 days and with maximum beta energies of 0.167 and 0.107 Mev. This particular listing is further confused by one of the few typographical errors noted.

In a book intended as a source of information it would seem desirable to list the best available values. When no attempt is made by the author to weigh the experimental values, a choice must be made by the reader who is probably much less qualified.

This is a very useful book in spite of the adverse comments. It contains a wealth of information brought together in a single place and will be extremely useful to any active worker in the fields of nuclear physics or nuclear radiation biology.

BOOKS RECEIVED

Atomic Energy and Society, by James S. Allen, International Publishers, New York, 1949, 95 pages, $1.25.

Max Planck—Scientific Autobiography and Other Papers, translated by Frank Gaynor, Philosophical Library, New York, 1949, 192 pages, $3.75.

OTHER LITERATURE

Atomic Energy Commission Document Sales Agency Price List No. 14. A listing of all publications made available for sale during August. *Copy of price list available without cost from U. S. Atomic Energy Commission Document Sales Agency, Box 62, Oak Ridge, Tenn.*

United States Atomic Energy Commission Contracting and Purchasing Offices and Types of Commodities Purchased. This booklet on how to do business with the AEC has been prepared to assist businesses interested in selling products used in the national atomic energy program. It is designed particularly to guide small business concerns.

The questions the booklet answers are: What is bought for the AEC? Who buys it? Where are the procurement offices located? It contains lists of the supplies, materials and equipment being purchased by or for the AEC and its contractors, the addresses of the purchasing offices and agents, and instructions on how a business firm may be considered to get invitations to bid.

Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, *D. C.*, 10 *cents.*

Isotopes—A Three-Year Summary of U. S. Distribution. The report summarizes the growth of the isotope distribution program during the three years it has been in effect, outlines methods of isotope production, and describes the typical ways in which isotopes are used in the United States and 21 foreign nations. It provides a useful measure of the value of isotopes to peacetime research by listing more than 1850 publications that have been issued on work done with these valuable products of the atomic energy program. The list is the most comprehensive bibliography yet published on research progress made through the use of Atomic Energy Commission-produced isotopes. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington* 25, *D.C.*, 45 *cents.*

Air Pollution in Donora, Pa. (Preliminary Report), Public Health Bulletin 306. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington* 25, *D. C.*, $1.25.

REFLECTIONS

This space will be used to publish, with the permission of the author, communications received in correspondence when the content is technical and believed to be of interest to our readers.

DEAR SIR:

The staff of the Isotopes Division has offered radioisotope users technical consultation in the disposal of their waste materials. Through the Advisory Field Service Branch of our organization, on-the-spot inspections of disposal facilities currently employed by radioisotope users are made and technical consultation on the preparation of radioactive waste for disposal is offered.

If any questions arise about the disposal of radioactive materials which have been procured through the Commission's isotope distribution program, the Isotopes Division would be pleased to receive such inquiries.

NATHAN H. WOODRUFF
Assistant Chief, Isotopes Division
Oak Ridge Operations
U. S. Atomic Energy Commission
Oak Ridge, Tennessee

DEAR SIR:

A new science always appears to require new words to describe new phenomena, and precise definitions of terms originally used rather loosely. That this is true of nucleonics at present is demonstrated by the great amount of effort being devoted to the preparation of a Glossary of Nuclear Energy Terms to be published by the National Research Council. I would like to propose three new words.

The word "hot" is used extensively, in both verbal and written nucleonic discussions, to designate conditions where radioactivity or nuclear radiations are at strengths dangerous to personnel. In this connotation it must be considered as slang, in the same way that "hot" indicates an electrified circuit, stolen goods, high powered automobiles, *etc.* In nucleonics this expression, while graphic, can be particularly confusing, since in most situations the nuclear reactions produce heat. Thus in a power reactor we have hot materials, "hot" materials, or hot, "hot" materials, to say nothing of the "hot" cold materials, *etc.*

To become accepted, a substitute word must accurately convey the meaning and be unambiguous, pronounceable and short. I have devoted considerable thought to this subject, and have discussed it with my colleagues over a period of more than a year. Their comments have been most helpful and have refined the original ideas considerably. In this time many synthetic words have been thought of and discarded for various reasons, but a long discussion of these labors seems inappropriate here. Instead, I shall propose for consideration only my final selections, reserving additional discussion for the future if these proposals elicit comments from others. The words I propose are:

1. *Radive* (RADio-actIVE)—The word radive indicates qualitatively the presence of nuclear radiation (or of radioactive materials) in such intensity (or concentration) as to offer exposure or ingestion hazards to personnel. It is offered as a substitute for "HOT."
2. *Tracive* (TRACer-level-radio-actIVE)
3. *Nondive* (NON-radioactIVE)

The definitions of 2 and 3 appear self-explanatory from the derivations given. I am indebted to Messrs. Parsegian, Taylor and Peaslee of our staff for the definition of *radive*.

WILLIAM B. SNOW
The Kellex Corporation
233 Broadway, New York 7, N. Y.

NUCLEONIC EVENTS

LILIENTHAL RESIGNS AS AEC CHAIRMAN

David E. Lilienthal, chairman of the United States Atomic Energy Commission, has resigned from that post, effective December 31. Lilienthal, whose resignation was accepted by President Truman, has been chairman of the AEC since it was first set up.

The other four commissioners are Gordon Dean, Sumner T. Pike, Henry D. Smyth and Lewis L. Strauss. Pike and Strauss are the only two of the original five commissioners remaining. W. W. Waymack and Robert Bacher, the other original commissioners, resigned recently.

RADIOTRACERS TO BE USED IN SHELLFISHERY RESEARCH

A cooperative research program on shellfish and other marine organisms will be carried on by the U. S. Fish and Wildlife Service and the Atomic Energy Commission, according to an announcement by Clarence Cottam, acting director of the Service.

The new research project—a survey of radioactivity in marine invertebrate animals—will be conducted at the U. S. Fisheries Biological Laboratory at Beaufort, N. C. The leader of the project is Walter A. Chipman, who for many years has engaged in studies on the nutrition, feeding and growth of oysters on the Atlantic coast. One main objective of the study is to learn more about the accumulation in marine life of radioactive material and its possible effects on shellfish. Another objective is to learn more about the natural foods required by oysters for growth and fattening. Conditioning oysters for market has always been a problem of oyster growers.

NAVY CONDUCTS ATOMIC ENERGY TRAINING PROGRAMS

The U. S. Navy is conducting a three-year postgraduate course in radiological defense training, according to an announcement by the Department of Defense. Civil Engineer Corps officers who take this course will study nuclear physics and radiochemistry.

Also, as part of its atomic energy training program, the Navy conducted a 14-day nuclear science seminar at Oak Ridge from November 30 through December 13. Sponsored by the Office of Naval Research, the planned seminar program included lectures and demonstrations of radiation effects on cells, human and animal, and discussion on shielding of nuclear reactors and atomic power as it applies to the Navy.

JAPANESE RECEIPT OF RADIOISOTOPES APPROVED

Approval of the participation of Japan in the program for the foreign distribution of radioisotopes has been announced by the Atomic Energy Commission.

Under an arrangement with the Department of the Army, exports of isotopes to Japan will be made through the headquarters of the Supreme Commander for the Allied Powers, and surveillance over Japanese research projects will be maintained by SCAP personnel to assure their safe and effective use. Japanese scientists will be

required to comply with the regulations governing the distribution of isotopes under the AEC's foreign distribution program.

NYU, AEC SPONSOR SAFETY CONFERENCE

A three-day conference on industrial and safety problems in nuclear technology, sponsored by New York University and the Atomic Energy Commission, will be held at the university in New York City next month. The conference, to be held January 10, 11 and 12, was planned by Sidney G. Roth, director of NYU's division of general education, and Walter Cutter of the university's center for safety education.

According to Professor Roth, the conference will attempt to meet the needs of industrial firms as well as technicians who want to know more about how atomic energy can be applied to peacetime uses.

The program is as follows:

January 10—Introduction and Welcome, Paul A. McGhee, NYU; Problems and Purpose of the Seminar, Myron A. Coler, NYU; Present Status of AEC Operations on Non-military Developments, W. E. Kelley, New York Office, AEC; Fundamental Particles and Rays, Serge A. Korff, NYU; Nuclear Energy Reactors and Apparatus, G. K. Green, Brookhaven; General Hazards of Nuclear Radiation, G. Failla, Columbia University; and Radioactive Materials: Production, Preparation and Shipment, Warren E. Winsche, Brookhaven.

January 11—Isotopes: Present and Potential Uses, Paul Aebersold, Oak Ridge; What Can Radioactive Isotopes Mean to Industry, Charles Rosenblum, Merck and Co.; General Health Problems and Safety Procedures in Tracer Work, Forrest Western, Oak Ridge; Prototype of a Radiochemical Laboratory and Auxiliary Equipment, Thomas Lanahan, Blickman; Instrumentation and Controls, V. Lawrence Parsegian, Kellex Corp.; and Radioisotopes, S. E. Eaton, Arthur D. Little Co.

January 12—Evaluation of Radiation Hazards and Their Control, Bernard S. Wolf, Medical Advisory Staff, New York Office, AEC; Waste and Water Pollution Problems, Abel Wolman, Johns Hopkins University; Insurance Problems, speaker to be announced; Sources of Information, George C. Manov, Oak Ridge; How to do Business with the AEC, Nathan H. Woodruff, Oak Ridge; Atomic Energy and Public Services (Fire, Water, and Waste), Edward Kehoe, New York Office, AEC; and Operation of a Radiochemical Laboratory, F. C. Henriques, Tracerlab, Inc.

On the evening of January 11, there will be a dinner, followed by a talk by Gordon Dean, member, AEC. Mr. Dean will speak on "New Horizons for Atomic Energy."

ASTM DISCUSSES INDUSTRIAL USE OF ISOTOPES

"Applying Man-Made Isotopes in Industry" was the title of the symposium held by the Detroit branch of the American Society for Testing Materials on October 27. The following papers were presented:

Significant and Historical Backgrounds on Isotopes, by Theodore M. Switz, director of industry relations for Nuclear Institutes, University of Chicago; Tracer Elements in the Inorganic Field, by Harrison Brown, Institute of Nuclear Studies, University of Chicago; Tracer Elements in the Organic Field, by Weldon G. Brown, professor of chemistry, University of Chicago; and Cautions and Precautions in the Use of Radioactive Isotopes, by Wendell C. Peacock, Sloan-Kettering Institute, New York.

16 PAPERS PRESENTED AT AEC-NRL GEIGER SYMPOSIUM

Sixteen papers on Geiger counters were presented at a symposium on this subject held at the Naval Research Laboratory on October 27 and 28. The meeting was one of a series sponsored by the Radiation Instruments Branch of the Atomic Energy Commission. The following papers were given:

Certain Problems in Geiger Counter Development, by W. F. G. Swann, The Bartol Research Foundation; Recent Experiments on Geiger-Müller Counters,

by C. G. Montgomery, Yale University; A Study of Spurious Discharges in Self-Quenching Geiger-Müller Counters, by S. C. Brown, Massachusetts Institute of Technology; An Investigation of Pulse Shape of Geiger Counter Discharge, by G. B. Kelley, Oak Ridge National Laboratory; Trends in Cosmic Ray and Geiger Counter Research in Europe Today, by S. A. Korff, New York University; Parallel Plate Counters, by L. A. Madansky, Johns Hopkins University; The Use of Geiger Counters in Biology and Medicine, by A. K. Solomon, Harvard Medical School; Relative Merits of Geiger and Scintillation Counters in Radiobiological Problems, by G. J. Hine, Memorial Hospital, New York; Low-Level and Absolute Gas Counting Techniques, by W. F. Libby, University of Chicago; Problems of Measuring Extremely Weak Activities, by H. R. Crane, University of Michigan; Thin-Window and "No" Window Counters for Beta Ray Spectrometer Measurements, by L. M. Langer, Indiana University; Low-Voltage Counters, by J. A. Simpson, University of Chicago; Photoelectric Thresholds in Photon Counters Containing Electronegative Quenching Gases, by Herbert Friedman, Naval Research Laboratory; Intercomparison of Different Counters for a Given Purpose, by Alexander Thomas, Tracerlab, Inc.; Present and Future Uses of Geiger Tubes in Industry, by J. A. Schoke, Nuclear Instrument & Chemical Corp.; A New Long-Lived Self-Quench Counter Filling, by L. C. Shore, Radiation Counter Laboratories.

TO DISCUSS AIR POLLUTION AT METEOROLOGY MEETING

The increased attention being given to the problem of air pollution is evidenced by two symposiums on the subject last month and one to be held next month. On January 3 and 4, an air pollution symposium will be held in St. Louis as part of the American Meteorological Society's national meeting (January 3–6).

This latter symposium is under the chairmanship of C. A. Gosline, E. I. du Pont de Nemours and Co. It will consist of two main parts. The first will be a panel discussion on the different phases of air pollution abatement, *e.g.*, enforcement, public health, equipment, industry, research, *etc.* The second part will be a series of technical papers which will emphasize the meteorological and climatological phases of air pollution and will cover such subjects as: urban diffusion of smokes, forecasting atmospheric dispersion conditions, dispersion from stacks and climate influences on pollution.

The symposiums held last month were the National Air Pollution Symposium in Pasadena (November 11, 12) and the annual meeting of the Industrial Hygiene Foundation in Pittsburgh at which one day (November 18) was devoted to industrial wastes.

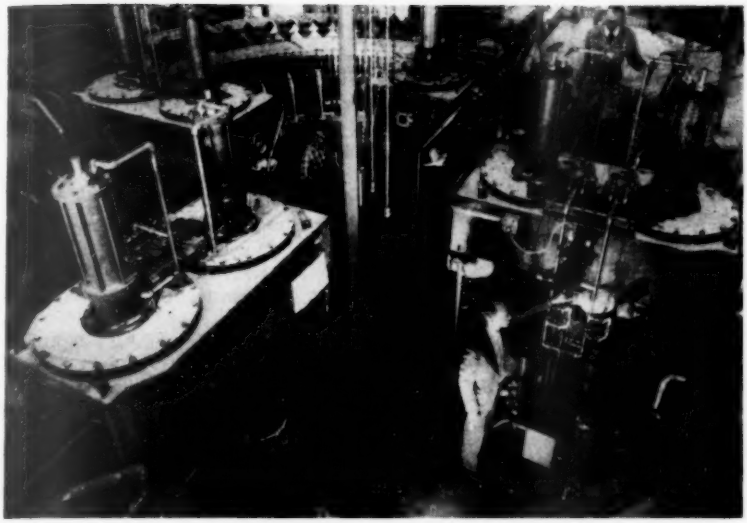
"U. S. APPLIED RESEARCH BEST," SAY G. E. SCIENTISTS

United States scientists lead the world in applications of technical knowledge, according to Dr. Robert H. Krieble, of the General Electric Research Laboratory. With his colleagues, Victor H. Fraenckel and Lyall Zickrick, he recently visited Europe, inspecting various technical and scientific activities.

Dr. Krieble declared, however, that European scientists are abreast of their American counterparts as far as fundamental work and quality of personnel are concerned. "European scientists are unusually original and imaginative but are hampered by lack of suitable facilities. There is no research in Europe comparable in extent with that in the United States," he stated.

Mr. Fraenckel gave particular credit to the British scientists who, he said, "are most penetrating and thoughtful as far as interpretation of their work is concerned."

The French, said Dr. Krieble, have been most productive of new developments, particularly in the field of chemistry. He declared that the French tend to look to America to apply the discoveries made by their scientists.



Prototype of the 6 Bev bevatron under construction at the Radiation Laboratory, University of California at Berkeley, this quarter-scale model is capable of accelerating protons to 6 Mev. Nearly oval shaped, the machine's electromagnet is divided into four quadrants, with two vacuum pumps attached to each. A small cyclotron at one of the magnet interspaces acts as an injector, firing 0.7 Mev protons into the 100-ft long accelerating chamber, which runs through and connects the magnet quadrants. Twenty-five feet in diameter, the model, now in operation, is shown here during construction with Dr. Edward Lofgren, in charge of development, in the right foreground.

One of the principal research centers visited was the new laboratory of the Associated Electrical Laboratories in England. About 50 scientists are engaged in research problems related to various phases of electricity and electronics.

Mr. Zickrick said that he was impressed with the London metallurgical laboratory of the British Non-Ferrous Metals Research Association. This activity, which has a large personnel and occupies a group of buildings, is operated jointly by a combine of over 450 companies, a cooperative feature which is characteristic of much industrial research in England.

He said that university research plays an important role in most European countries and cited as examples, the low-temperature work at the Universities of Bristol, Oxford, and Cambridge, in England, and Leyden, in Holland, which is outstanding in this field.

The scientists said that despite tremendous difficulties, research in the Western Zone of Germany is rising. One interesting project, cited by Dr. Krieble, is the Suddeutsche Laboratory at Mosbach-Baden, operated jointly by a group from Allgemeine Elektrizitat Gesellschaft, principal German electrical company, and Carl Zeiss Works, the famous optical concern. These scientists and engineers have designed a new and simplified type of electron microscope which they are producing and selling, using the profits to finance further research.

Dr. Krieble and Mr. Fraenckel both visited Switzerland, and they described it as "an oasis in Europe," the least

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affected by the war of any nation they saw. "The Swiss Industrial Fair at Zurich," said Dr. Krieble, "shows their great engineering skill in products from watches to heavy machinery." They said that the Swiss are among the finest engineers of Europe.

ATOMIC ENERGY PROBLEMS DISCUSSED AT IBM FORUM

Various problems in atomic energy were discussed at the scientific computation forum sponsored by the International Business Machines Corporation and held at Endicott, N. Y., November 16 to 18. The following were among the papers presented:

Shielding Calculations, by Robert Echols, head, shielding project, NEPA Project, Oak Ridge; Modifications of the Monte Carlo Method, by Herman Kahn, RAND Corp.; Dynamics of Nuclear Fission, by David L. Hill, Vanderbilt University; Analyzing Exponential Decay Curves, by Alston S. Householder, Oak Ridge National Laboratory; Eigenvalue Problems Related to the La Place Operator, by Donald A. Flanders, Argonne National Laboratory, and George Shortley, Johns Hopkins University; Stochastic Methods in Statistical and Quantum Mechanics, by G. King, A. D. Little Co.; and Calculations of Resonance Energies, by George Kimball, Columbia University. John von Neumann, Institute for Advanced Study, Princeton University, delivered an address on the future of computing machines in their relation to physical and social sciences.

GENERAL ELECTRIC CO. FELLOWSHIPS AVAILABLE

Applications for General Electric Company fellowships for the 1950–51 academic year will be accepted until January 1st, according to a recent announcement.

The Charles A. Coffin fellowships are awarded in the fields of electricity, physics and physical chemistry, while the Gerard Swope fellowships are awarded in engineering, industrial management, the physical sciences, and other scientific and industrial fields.

Awards to an annual maximum of $1,500 for each fellowship will be made, the amount depending on the needs of the student. A $500 grant may be made for specific apparatus or other expense in connection with the research of the fellow. In addition, in cases of need, loans up to $1,000 may be granted.

Applications may be obtained from A. D. Marshall, secretary, General Electric Educational Fund, Schenectady, New York.

WINTER COURSES AVAILABLE IN OAK RIDGE INSTITUTE

Some vacancies still remain for the winter series of three radioisotope techniques courses offered by the Special Training Division of the Oak Ridge Institute of Nuclear Studies, according to an announcement by the Division.

The courses will begin on January 2, January 30, and March 6. Applications should be made as soon as possible. Requests for application and additional information should be addressed to Dr. Ralph T. Overman, Chairman, Special Training Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tennessee.

NEW LAB BUILDING FOR LIVERPOOL UNIV. COMPLETED

The building for the new nuclear physics laboratory at Liverpool University, England, has been completed, according to a recent announcement. The building will house a 400-Mev synchro-cyclotron which is expected to be ready for use next year.

NUCLEAR NEWSMAKERS

Ward F. Davidson, research engineer for the Consolidated Edison Company of New York, discussed the future of nuclear power at the 12th annual joint fuels conference of the American

Society of Mechanical Engineers and the American Institute of Mining and Metallurgical Engineers at French Lick, Ind., on October 26.

Norman R. Beers, Editor, NUCLEONICS, spoke on "Meteorology as a General Factor in Air Pollution Problems" on November 11 at the National Air Pollution Symposium at Pasadena, Calif.

Glenn T. Seaborg, University of California Radiation Laboratory, on his recent trip abroad, spoke before the Swedish Royal Academy of Sciences on the subject of the transuranium elements.

Henry G. Davey has been appointed head of the atomic explosives factory at Sellafield, West Cumberland, England.

Thomas J. Parmley, former consultant in nuclear physics to the University of California Radiation Laboratory, has been appointed to the staff of the National Bureau of Standards, where he will do research in the X-ray laboratory of the Atomic and Molecular Physics Division.

William F. Bale, professor of radiation biology at the University of Rochester Medical School, has been appointed to the staff of the Atomic Energy Commission as radiobiologist of the Division of Biology and Medicine. Dr. Bale, who is on leave from the university, will be responsible for the biological and health aspects of the AEC's waste disposal program.

Edward M. Corson, senior physicist at Armour Research Foundation of Illinois Institute of Technology, will lecture in the graduate school, do research work, and participate in several international conferences at the University of Edinburgh, Scotland.

On leave of absence from the Foundation for one year, to accept the post. He expects to assume his duties in Edinburgh late in October.

Corson will serve on the faculty of the graduate department of mathematical physics. The subject of his research work will be "Field Theory of Elementary Particles."

Roger S. Warner, former director of engineering of the Atomic Energy Commission, has joined the staff of Arthur D. Little, Inc., Cambridge, Mass.

J. K. Gustafson, manager of the AEC Raw Materials Operations Office, **Thorold Field** and **Robert Macdonald,** technical advisers to Dr. Gustafson, and **A. A. Wells,** special assistant to the AEC General Counsel, visited the Union of South Africa last month to discuss problems relating to the production of uranium in the Union of South Africa. Representatives of Great Britain also participated.

George G. Gallagher has been appointed assistant manager of the Raw Materials Operations Office of the Atomic Energy Commission. He replaces **Jesse C. Johnson,** who recently became deputy manager.

James B. Fisk, former director of research of the Atomic Energy Commission and professor of applied physics at Harvard, has been named physical research director of Bell Telephone Laboratories to replace **Harvey Fletcher,** who has retired.

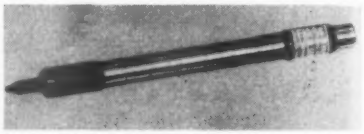
David C. Minton, Jr., has been named executive in charge of sponsor relations and projects development at Battelle Memorial Institute, Columbus, O. He will act in a liaison capacity between Battelle and industrial and government sponsors conducting research at the institute.

Wallace Waterfall, formerly director of research and product development for the Celotex Corporation, has been appointed to the newly created position of Executive Secretary of the American Institute of Physics.

PRODUCTS and MATERIALS

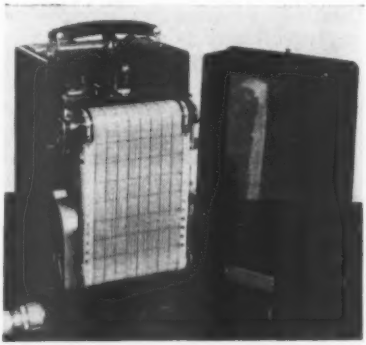
HIGH-TEMPERATURE GAGE

Fairchild Camera & Instrument Corp., West Coast Division, 53 W. Union St., Pasadena, Calif. Accurate measurement of gas temperatures of more than 5,000° F is claimed for the model 263 gas temperature indicator. A water-cooled stainless-steel probe is used to obtain small samples of the gas to be measured. The probe may be manipulated to obtain a temperature traverse of the gas stream under test. The sample is passed through a small iridium orifice, cooled, and passed through a second metering orifice and manually operated pressure reducing valve to atmosphere. The differential pressure drop across the iridium orifice, when the reducing valve is adjusted properly, is a linear function of the absolute temperature of the gases being measured. A differential pressure gage indicates the temperature of the gas.



METAL WALL COUNTER TUBE

Amperex Electronic Corp., 25 Washington St., Brooklyn 1, N. Y. Filled with neon and a quenching admixture, the type 52N beta and gamma counter was designed for operation in the range from −55 to 75° C at 700 volts d-c. The stainless-steel thin metal wall has a thickness of 30 to 40 mg/cm² and is 3 in. long. A plateau in excess of 200 volts with maximum slope of 10% per 100 volts is claimed. Terminal capacitance is 2.4 $\mu\mu$f. Deadtime is approximately 100 μsec. Unlimited life is claimed, with 5×10^{10} counts guaranteed.



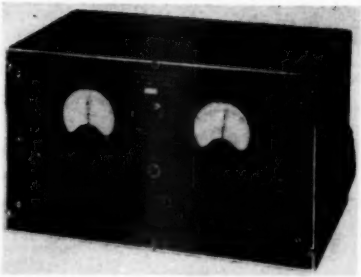
COUNTING RATE RECORDER

Berkeley Scientific Co., 6th and Nevin Ave., Richmond, Calif. The model 1500 recording counting rate computer

is designed to record rapidly changing counting rates. It is claimed that the "memory" effect (slow response time) usually present in counting rate meters is eliminated. The output pulse from an electronic scaler is used in the computer to make a small mark on the strip chart such that a plot of counting rate vs time is obtained. Three marking speed ranges are provided, and chart speed may be varied over a 60–1 ratio with a quick-shift lever.

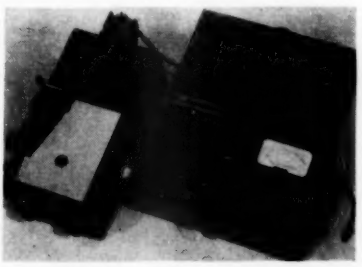
BETA-GAMMA SURVEY METER

Victoreen Instrument Co., 5806 Hough Ave., Cleveland, Ohio. The model 263B beta-gamma survey meter is a modification of the model 263A. More rugged construction, decreased height, and decreased weight are claimed. Use of a 1B85 thyrode and two 5828 medium-mu triodes are said to improve accuracy and reliability. The meter has three ranges, with full-scale sensitivity of 130, 1,300, and 13,000 counts per sec. Average intensity of beta and/or gamma radiation in mr/hr may be read from a microammeter which has been calibrated against the gamma rays from radium. The counter tube is housed in a probe which mounts on the outside of the case and which is capable of detecting individual ionizing particles.



REGULATED POWER SUPPLY

Oregon Electronic Mfg. Co., 206 S. W. Washington St., Portland 4, Ore. Operating from a 110–130 volt a-c line, the model A3 power supply provides a regulated d-c output which is continuously variable from zero to 400 volts at no load and from zero to 250 volts at 200 milliamperes drain. Regulation of 0.5% is claimed; ripple voltage is less than 10 millivolts. Three other outputs are also provided: 400 volts d-c unregulated, zero to −150 volts d-c variable and stabilized, and a filament supply of 6.3 volts a-c at 5 amperes. A 40 μfd capacitor may be switched across the regulated output to accommodate large peak current loads.



DENSITOMETER

Photovolt Corp., 95 Madison Ave., New York 16, N. Y. The model 500-R radiation detection densitometer is a photoelectric instrument designed for the measurement of the optical density

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of X-ray films for determination of exposure to radiation. Optical density of film is read directly from a scale which has density ranges from 0 to 1 and from 0 to 2. A switch is provided for shifting scales, and provision is made for reading either absolute or relative densities. The phototube unit is mounted on a swing arm. A built-in automatic shutter is opened during measurements by depressing a pushbutton.

ACTINIUM ISOLATED

International Rare Metals Refinery, Inc., 630 Fifth Ave., New York, N. Y. Industrial production of the radioactive element actinium has been announced by this company. By means of a process developed by Boris Pregel, the element with its decay products has been isolated in quantity in a highly purified form, and will be available commercially in the near future. Prior processes yielded only submicroscopic quantities of actinium.

COUNT RATE METER

Radio Corporation of America, Camden, N. J. The type EMA-6 count rate meter provides scales of 0–10, 0–100, and 0–1,000 counts/sec for indicating average counting rate of G-M tubes. Operating from a 115-volt 60-cycle line, it is provided with internal calibration, achieved through use of rectified pulses from the line. A built-in G-M tube voltage supply is continuously variable over the range from zero to 2,400 volts d-c. The meter shunt capacitor is equipped with a shorting switch for rapid zeroing of the meter pointer. Headphones for aural monitoring at low counting rates can be plugged into the jack provided.

RESIN COATING

Carboline Co., 7603 Forsythe Blvd., St. Louis 5, Mo. B Resin Solution, a newly developed polymer, is a semithermoplastic, semithermosetting ready-mixed resin coating, the molecular chain length of which slowly increases with age in a deposited film. Made for application at room temperature, it requires no mixing and is flexible when dry. Chief advantages claimed for this new coating over polyvinyl chloride and chlorinated rubber coatings are: resistance to acids of higher concentrations, resistance to higher liquid temperatures (180–200° F), and resistance to solvents such as alcohols and straight chain chlorinated and aromatic hydrocarbons. A limited quantity is available at no charge for experimental and test purposes to those who will give information on its application.

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(Continued on page 86)

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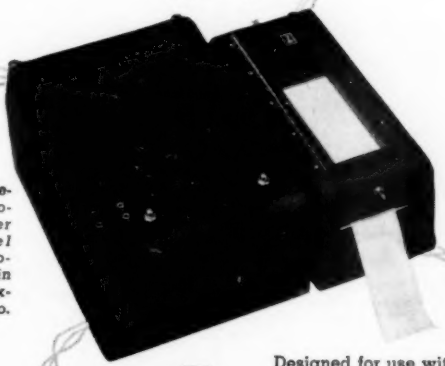

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Products and Materials *(Continued)*

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RESUME PRODUCTION

Landsverk Electrometer Company, Pippin Road, Cincinnati 31, Ohio, was reactivated on November 1st. The company specializes in the development and production of quartz fiber types of instruments. Included are survey meters, pocket dosimeters, pocket chambers and auxiliary units. The company is headed by O. G. Landsverk.

LITERATURE AVAILABLE

Castaloy Laboratory Appliances. Corrosion-resistant laboratory clamps, burette holders, supports, and devices for controlling flow through flexible tubing are described in this catalog. *Fischer Scientific Co., 717 Forbes St., Pittsburgh 19, Pa.*

Nuclear Physics Laboratory Manual. Designed to be used with a teaching kit containing cloud chamber photographs of particle tracks, this booklet has sections on elementary particle physics, on interpretation of track photographs, on film data and processing instructions, and on laboratory apparatus for examining track plates. *Heinicke Instrument Corp., 315 Alexander St., Rochester, N. Y.*

Consolidated-Nier Isotope-Ratio Mass Spectrometer, Model 21-201. Application of the instrument to the use and measurement of stable rare isotopes is covered in this booklet. Operating characteristics and data are included, and isotope tracer and isotope dilution techniques are discussed. *Consolidated Engineering Corp., 620 N. Lake Ave., Pasadena 4, Calif.*

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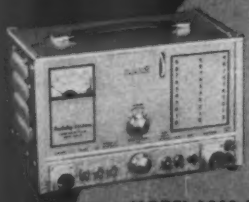

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